ALBERTA BUILDING ENVELOPE FAILURE ANALYSIS

Alberta
MUNICIPAL AFFAIRS
Innovative Housing Grants Program

ALBERTA BUILDING ENVELOPE FAILURE ANALYSIS

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FOREWORD

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EXECUTIVE SUMMARY

The walls, in particular, and building envelopes, in general, of less than twenty year old medium and high rise residential buildings in Alberta have shown a marked reduction in performance. The principal objective of this study was to develop recommendations and strategies which, when applied to the design, construction and maintenance of envelopes of the subject building categories, will significantly reduce the incidence of envelope failure and will result in a minimum cost, maximum benefit relationship in instances where envelope repair is required.

The building envelope consists of those components of a building assembly that provide a barrier between the indoor and outdoor environments. The purpose of the barrier is to maintain the indoor environment within acceptable limits of temperature and humidity for its occupants. The building envelope is composed of wall and roof elements, as well as below grade construction. This study concentrates on the wall component of the envelope.

The design requirements for the building envelope and in particular the exterior walls, are clearly explained by N.B. Hutcheon in the Canadian Building Digest Number 48 (CBD 48), of the Division of Building Research, entitled *Requirements for Exterior Walls*. Of the eleven goals listed, we have primarily addressed the first four: control heat flow; control water vapour flow; control air flow; control rain penetration.

There are two basic wall system types, the face-sealed system and a system based upon the rain screen principle. A face-seal refers to a system whereby the barrier to air and water infiltration is the exterior face of the cladding. A rain screen provides a pressure-equalized and drained space between the cladding and the air and water sealed backup wall. The rain screen is technologically superior to the face sealed system.

There is little in the way of legislated standards for building envelope performance. It is possible to construct a building that "meets code" and yet have an envelope that performs poorly.

There exists a large body of technical publications regarding the principles of design and construction of the building envelope. A partial list of those publications is contained in the Bibliography.

In Alberta, the construction of medium and high-rise residential buildings started in 1963 with the vast majority of the structures constructed during the period from 1970 to 1982. The most prevalent wall assembly consists of a steel stud backup wall combined with one of three cladding systems; stucco, brick veneer or precast concrete wall panels.

For the purposes of this study, information on forty-six buildings was obtained by actual investigations, telephone interviews and from investigations previously performed by Morrison Hershfield Ltd.. To aid in data analysis the information obtained has been organized into a table of building records (Table 1). The information has been listed under five main categories; General Information, Wall Assembly Components, Quality, Cost of Repair and Comments. A somewhat subjective rating system for the envelope was established, those ratings being "Failed", "Will Fail" and "OK". Quality of design, construction and maintenance were rated as Good, Average or Poor. Where sufficient information was available, cost of repair was calculated on an average cost per suite basis.

Although there are some limitations and biases in the information obtained we have been able to conclude that close to half of all high-rise apartment buildings constructed in Alberta since the early 1960's are suffering or have suffered major envelope problems. The majority of the problems reported with exterior walls were related to water penetration and by far the majority of those were related to windows.

The most common cause of failure for the wall assembly are:

- Poor workmanship and/or lack of inspection.

- Ignorance of, or choosing to ignore recognized standards of construction.

- Use of inappropriate or out-dated technology

- Failure to take into account movement and deflections in the main structure due to wind and live loads, creep and broad temperature changes.

- Failure to take into account pressure differentials across the building envelope due to wind and aerodynamics, the H.V.A.C. system, and stack effect.

- Failure to take into account the high humidity conditions in residential buildings (as opposed to office buildings).

- Failure to take into account the major structural penetrations of the building envelope at balconies.

The primary function of the envelope is to control the movement of air, moisture and heat through the assembly. When there is a failure in any one of these areas, a very complicated cause and effect interaction is almost always initiated. This cause and effect interaction is simplified and represented graphically in the Cause and Effect Chart (Figure 13). Every building envelope failure can be traced back to an error or omission on the part of the people involved. Accordingly the chart has two main parts, one part addresses the human aspects of the problem and the other the technical aspects.

On the human side of the equation, there is no substitute for the proper selection of quality materials, good technical design, or high quality workmanship and maintenance. On the technical side, the most effective way to break the cause and effect chain is to utilize the rain screen principle when constructing a wall assembly.

Following is a list of some specific recommendations:

- Provide a tight air and water building seal, especially at major junctions such as roof/wall connections and windows.

- Install insulation continuously on the outside of the structure.

- Install good quality windows.

- Provide drainage from wall cavities.

- Use flexible membranes with mechanical connections, as opposed to caulking, to seal joints.

- If caulking must be used, ensure the design of the joint is appropriate; the correct sealant is employed; the surfaces are compatible, clean and primed; and the installation done by a skilled tradesman.

It became very evident, when researching this report, that very little protection is afforded the buyer of a high-rise apartment building or apartment condominium. As an alternative to "Caveat Emptor", the report suggests consideration be given to the establishment of a standard rating system for the technical evaluation of buildings.

Building envelope design principles are not new. The recent increase in failures in the subject group of buildings could have been avoided if those basic design principles were followed. The design community now appears to be addressing those problems (albeit belatedly) but developers, the construction industry, maintenance personnel and owners are still somewhat naive. It is hoped that this document will assist in the understanding and avoidance of building envelope failures.

1.0 INTRODUCTION

1.1 The Problem

The walls, in particular, and building envelopes, in general, of less than twenty year old medium and high rise residential buildings in Alberta have shown a marked reduction in performance. This poor performance has manifested itself in many ways, including such problems as the corrosion of precast anchors, spalling of brick and block veneer, icicle and ice formation on exterior facades and on the interior of wall cavities, staining and efflorescence on masonry, uncontrolled interior temperatures, frozen pipes in cavities, displaced stonework, rain penetration and high energy costs for both heating and cooling. The end result of this poor performance has been high maintenance and repair costs and, on occasion, danger to the public.

1.2 Objectives

Morrison Hershfield Limited undertook this research to study the extent and mode of failures in the wall component portion of building envelopes of residential medium and high rise buildings in Alberta. The principal objective of this study was to develop recommendations and strategies which, when applied to the design, construction and maintenance of envelopes of the subject building categories, will significantly reduce the incidence of envelope failure and will result in a minimum cost, maximum benefit relationship in instances where envelope repair is required.

1.3 Scope and Focus

This study is focused upon wall assemblies. It encompasses the investigation and analysis of envelope failures in medium-rise (4 to 6 storeys) and high-rise (7 storeys or more) residential buildings. Varying amounts of information were obtained on fourty-six buildings located in six communities in Alberta.

1.4 Study Organization

Part Two discusses the building envelope: definition; performance criteria; types of systems; joint design. An overview of legislated standards (ie: the National and Alberta Building Codes) and technical reports and studies is provided.

Part Three addresses medium and high rise apartment construction in the Alberta context. Climate and historical background are discussed.

Part Four is the Building Envelope Survey. The methods of data collection and organization are outlined, and a system of rating the various component parts of an assembly is established. The data is analysed on the basis of the component parts and correlations are drawn (wherever possible) with such items as location, year of construction, cost of repair, etc. A summary of our interviews with Alberta Mortgage and Housing, Canada Mortgage and Housing, design consultants and contractors is provided.

The conclusions contained in Part Five include discussions on the cause and effect of envelope failures and the technical solutions to these problems.

Our recommendations in Part Six include strategies for avoidance and repair of envelope problems, and suggested areas for further research. We have also recommended that a measure of building quality be established to protect the unsophisticated buyer.

1.5 Present Status of Envelope Design

There presently exists a readily available, large body of theoretical and practical design guidelines for building envelope construction. This study should impress upon the developer, the design community, the construction industry, owners and maintenance personnel, the importance of following those guidelines.

2.0 THE BUILDING ENVELOPE

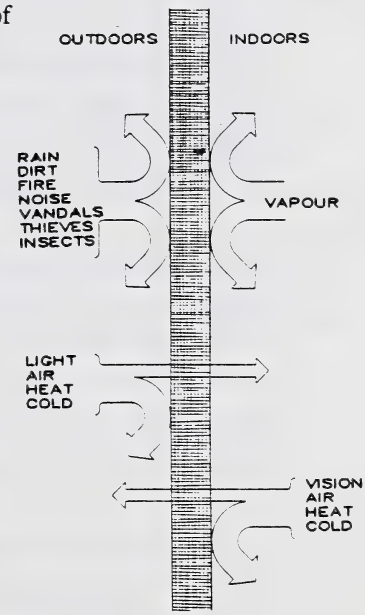
2.1 What is a Building Envelope?

The building envelope consists of those components of a building assembly that provide a barrier between the indoor and outdoor environments. The purpose of the barrier is to maintain the indoor environment within acceptable limits of temperature and humidity for its occupants. The building envelope is composed of wall and roof elements, as well as below grade construction. This study concentrates on the wall component of the envelope. The exterior wall comprises walls, windows and doors and includes the connections to the foundation and roof.

2.2 Performance Criteria

The design requirements for the building envelope and in particular the exterior walls and cladding systems, are clearly explained by N.B. Hutcheon, in Canadian Building Digest Number 48 (CBD 48), of the Division of Building Research, entitled *Requirements for Exterior Walls.* In this 1963 Digest, he lists 11 goals that must be considered in the design of all exterior walls:

1. Control heat flow
2. Control water vapour flow
3. Control air flow
4. Control rain penetration
5. Control light, solar and other radiation.
6. Control noise
7. Control fire
8. Provide strength and rigidity
9. Be durable
10. Be aesthetically pleasing
11. Be economical



The Wall as Filter

Figure 1

The first seven requirements (illustrated graphically in Fig. 1) relate to the function of the exterior wall as an effective barrier between the outdoor and indoor environment and are the subject of this work. These requirements must all come into play in the design and construction of an exterior wall, and affect the performance of the wall system. The next four relate to the overall requirements of the building, but also play an important role in the final choice of the systems to be used.

Unfortunately, there is lack of understanding of the importance and implications of building envelope performance criteria within the design and construction industries, especially with regard to the first four requirements: heat, vapour and air flow, and rain penetration. Following is a short discussion of the current theory on those four requirements.

2.2.1 Control Heat Flow

Provision of an expected human comfort level and economic considerations are the reasons for wanting to control heat flow. In the early part of this century, it was normal to expect building interiors to be chilly and drafty and to have exterior walls that were cold and damp. Today, most Albertans expect an indoor environment that is maintained between $20^{o}C$ and $24^{o}C$, has reasonable levels of humidity, is draft free and has exterior walls that are warm and dry to the touch (See *Thermal Environment and Human Comfort*, CBD 102, N.B. Hutcheon).

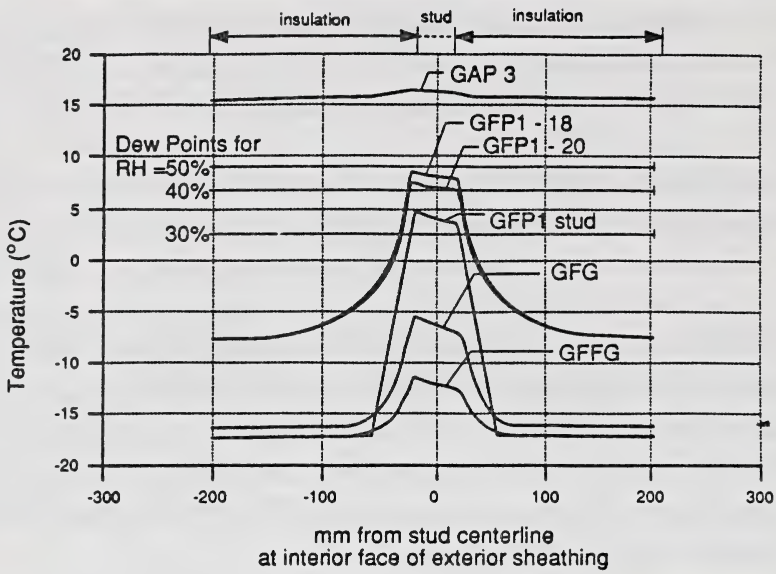
Most of the present day expectations can be met by simply increasing the amount and distribution of heat, but rising energy costs have made this solution economically impractical. In order to conserve energy, the heat flow through the envelope must be reduced. This is accomplished by reducing the air flow through the assembly (addressed later in this discussion) and by increasing the thermal resistance ("R or R.S.I.-value") of the envelope. W.H. Ball states:

> "With few exceptions the basic constructions employed in dwellings do not of themselves provide sufficient insulating value. It is necessary or desirable in most cases to add a layer of insulation to improve the overall resistance to heat flow. Ideally, it would be best if this insulating material could be applied in a manner similar to that of clothing on a person. In

> this way the insulation would be continuous over the building and its structure would be protected from the extremes of temperature both summer and winter." *(Thermal Insulation in Dwellings*, CBD 16.)

This is easier to state than to put into practice. Whether in simple homes or complex multi-storey buildings, gaps, sags or otherwise poorly installed insulation and structural penetrations provide thermal bridges for heat loss. Studies have shown that a space of only 3mm between the insulation and the interior, in which exterior air is allowed to circulate, can cause at least a 30% reduction in the efficiency of the insulation. Most insulating materials, by their nature, are not very durable and must be protected from the environment with a cladding material. Structural support, most commonly metal studs, for that cladding almost always necessitates a discontinuity (thermal bridge) in the thermal envelope at that location.

It was not until the Eighties that designers became concerned with the thermal bridge occurring at each stud location. Most, if not all, recent structures have a layer of insulation applied to the face of the sheathing in order to reduce the effect of that thermal bridge. There was an interesting test done by C.M.H.C., and published in the Seminar on Brick Veneer Wall Systems (See Figure 2, Temperature Profiles for Various Veneer Wall Systems, page 6) pertaining to the effects of insulation placement in relation to steel studs and the resulting dew point locations. The Y-axis plots temperature measured at the interior face of the exterior sheathing while the X-axis is a measure of distance from the centreline of stud. Of the five assemblies tested, the one with insulation located only on the exterior of the sheathing (GAP 3), is the sole assembly that has all temperatures above the dew point.



GAP3 = wall with no insulation in stud space and 75 mm rigid insulation on the outside

GFPI-18 and GFPI-20 = wall with fiberglass in stud cavity and 25mm polystyrene exterior sheathing. 18 and 20 guage studs were used.

GFPI stud refers to the case where rigid insulation was just put over the exterior flange of the stud

GFG is the standard wall with no exterior insulation

GFFG is the standard wall but with a 25 mm layer of fibreglass on the interior face of the stud/

TEMPERATURE PROFILES FOR VARIOUS WALL CONFIGURATIONS

(Seminar on Brick Veneer Wall Systems - Drysdale Et Al)

Figure 2

There appears to be a consensus of opinion within the building science community that the optimum assembly has all the insulation outboard of the studs on the plane of the sheathing. The air and vapour barrier would then be located at the face of the sheathing. This provides a number of advantages: first, the air/vapour barrier is in the same location on the warm side of the insulation; second, there is virtually no thermal bridging at the stud location or edge of slab; third, by being applied on the exterior face, there are fewer obstructions to maintaining a complete seal; fourth, the interior face of the wall can be penetrated

at will for such things as convenience outlets, etc., without fear of damaging the building envelope. The disadvantages are: first, the assembly is quite thick, although the stud size may be reduced as it is now predicated on wind load and not on insulation thickness; second, the cladding must be supported some distance off the main structural frame; and third, if problems occur the assembly can only be accessed by removing the outer cladding.

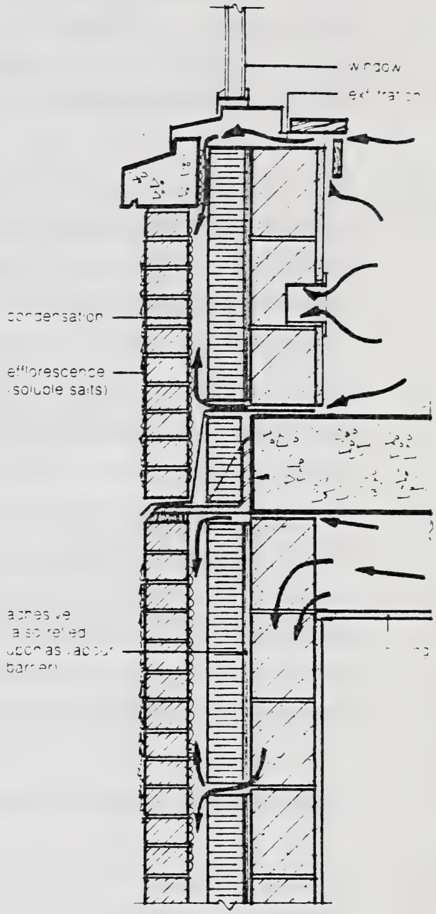
The recent requirement for increased thermal efficiency has introduced some new problems to be considered. Disregarding comfort and energy costs, older, poorly insulated assemblies had few problems since the entire wall was constantly kept warm and air movement was relatively unimpeded. If moisture did gain entry to the assembly, either by rain penetration or condensation, it was not allowed to freeze and the air movement provided a good drying mechanism. In new assemblies with high thermal resistance, it is certain that some components of the assembly will be below the dew point, and, in some circumstances below the freezing point (See *Temperature Gradients Through Building Envelopes*, CBD 36, J.K. Latta and G.K. Garden). If moisture is allowed to accumulate in such an assembly, whether by vapour transmission, air leakage, or rain penetration, substantial damage to the components is bound to occur. Therefore, if damage is to be avoided in well insulated assemblies, control of vapour transmission, air leakage and rain penetration must be a priority.

2.2.2 Control Vapour Flow

Control of vapour flow through a building envelope is not considered as important as it once was. Air leakage has been shown to be the prime cause of most condensation problems (See *Vapour Barriers: What are They? Are They Effective?*, CBD 175, J.K. Latta). This is not to say that vapour control can be ignored. However, if air leakage is reduced to a minimum, then vapour control, in normal circumstances, can be effectively accomplished with something as simple as two coats of oil based paint on a suitable substrate.

2.2.3 Control Air Flow

In many buildings air leakage through the building envelope has been identified as the number one problem (See *Control of Air Leakage is Important,* CBD 72, G.K. Garden). Although most new buildings have more wall and roof insulation than older buildings, the cladding, wall and envelope damage due to even limited air leakage through the building envelope has increased markedly. With more insulation in walls, claddings are subject to wider extremes of temperatures; the outer wall elements are maintained at or near the outside temperature. The colder cladding then triggers more condensation with subsequent water damage. Moist, humid air flowing through a building envelope in an uncontrolled fashion often results in the above mentioned problems, thereby causing damage to the claddings and exterior walls of new buildings. Typical pathways for air exfiltration are shown in Figure 3.



Typical Pathways for Air Exfiltration

Figure 3

The amount of air moving through any opening in the envelope is in direct proportion to the pressure difference across that opening. Pressure differences can arise from wind or stack effects and from the mechanical ventilation system.

Wind - Wind will cause an overpressure on the windward face of a building and a suction pressure on the leeward face. Although the effects of wind are well

understood, little, if anything, can be done to control these natural effects on building pressurization.

Stack Effect -Stack effect in buildings is the same as the stack effect in chimneys, ie: hot air rises. This results in the upper portion of the building becoming positively pressurized and the lower portion negative. There are methods that can reduce, but not eliminate, stack effects such as: increase air tightness of exterior enclosures and interior separations and, adjust air handling systems to provide an imbalance of supply or exhaust (See *Stack Effect and Building Design,* CBD 107, A.G. Wilson and G.T. Tamura).

Mechanical Ventilation - Building pressurization is affected if the ventilation system exhausts more or less air than is taken in. Management of pressurization is dependant upon the sophistication of the system and its controls.

It is clear that pressure differences across the envelope cannot be avoided. Since infiltration of cold dry air is less damaging to the wall assembly than exfiltration of warm moist air, it follows that it would be preferable to maintain a slight negative building pressure. If the envelope is poorly sealed against air leakage, even the most sophisticated ventilation system would not be sufficient to maintain a negative pressure. One is led to the conclusion that uncontrolled air flow across the envelope must be reduced to an absolute minimum, especially in tall structures where wind and stack effects have the most impact.

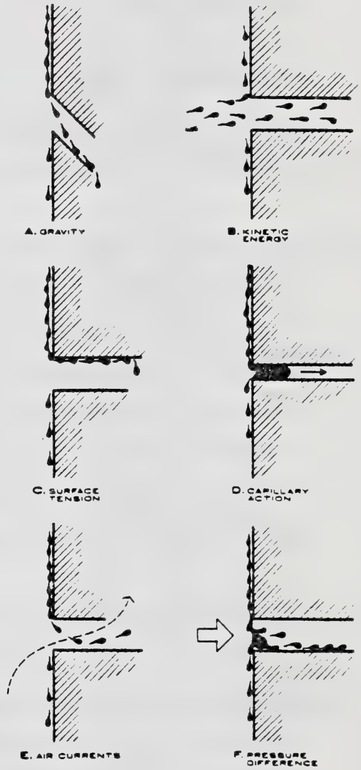
As a result of growing concern regarding the effect of uncontrolled air leakage in buildings, the National Building Code of Canada and the Alberta Building Code now includes a new requirement, Section 5.3 "Control of Air Leakage, Subsection 5.3.1, Air Barriers". It requires that all new buildings incorporate an "effective" air barrier within the building envelope. This requirement is now mandatory in all provinces (Alberta included) that have adopted the 1990 edition of the National Building Code of Canada (N.B.C., 1990).

It must be remembered that for an air barrier to be "effective" it must be continuous. This means the barrier is not simply a membrane but a system of components that provides resistance to air movement. Those components might include the roof membrane, wall sheathing, door and window frames, glass lights

and the foundation walls. Not only is the resistance of the components important but the seal of the connections between those components is also. The connections may be caulked, gasketed or have a flexible membrane applied. The nature of the connection is dependant upon whether it is exposed to weather, extreme temperature differences, structural movement and whether the connection is accessible for maintenance.

2.2.4 Control Rain Penetration

Historically, rain penetration through cladding systems is one of the most persistent problems affecting the performance of wall systems. Water can penetrate through to the interior of the assembly if and only if there is an opening and a driving force. The forces are gravity, kinetic energy, surface tension, capillary action, air currents and pressure differences, as illustrated in Figure 4. (See *Rain Penetration and its Control*, CBD 40, G.K. Garden)



Forces for Rain Penetration

Figure 4

It is nearly impossible to make a building envelope completely rain-tight, therefore it is prudent to design for that eventuality. There are a few seemingly obvious rules that should be followed:

1. Water flows downhill - let gravity do the work for you. Surfaces, such as flashings or brick ties should be sloped away from the assembly rather than towards the interior.

2. Provide drips on the underside of components to break the surface tension of the water thus allowing it to fall free.

3. Provide a pressure equalized void behind the cladding to remove the kinetic energy provided by wind or pressure differences across the envelope. This is the primary function of a rain screen wall.

4. If water can get in (and it almost always can) allow it to drain out. This is also crucial to the function of a rain screen wall. In most cases the components of a wall assembly are not adversely affected by the occasional dampness. Very few of those components, however, can withstand "having wet feet" for extended periods of time .

5. In addition to drainage, it is important to provide air circulation around those components outside the line of insulation and air barrier to allow for drying. (Never allow outside air to circulate around the warm side of the insulation - see Control Heat Flow above.)

6. Protect components that are subject to deterioration through contact with water. Exterior grade gypsum board is NOT waterproof. Ensure all steel components such as anchors and ties are hot dipped galvanized, not just painted.

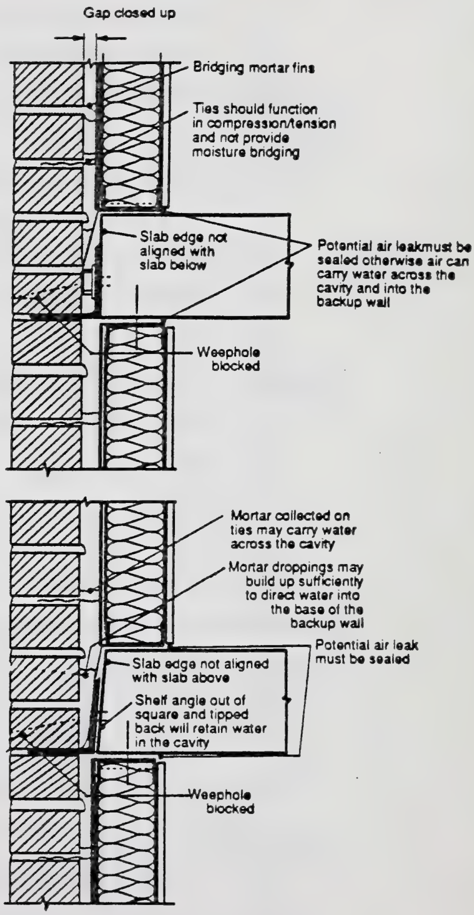
Control of vapour and air flow, and of rain penetration, is intended primarily to ensure that water does not accumulate in the wall assembly. This concern is not limited to the damage that can be done to moisture sensitive materials, but also because of the destructive forces that can be generated when the moisture freezes. Water is unique in being the only substance that expands as it freezes. When a material containing water freezes, the resulting volumetric expansion can often damage the material if it is incapable of accommodating external expansion. Water also enters building material from the accumulation of snow and ice. During spring when temperatures rise and melt water gravitates downward, it is often directed into cavities and in areas where it was not intended to go. The combined action of temperature and melt water can produce repeated freeze/thaw cycles which will aggravate deterioration caused by water in the assembly.

2.3 Wall System Types

There are two basic wall system types, the face-sealed system and a system based upon the rain screen principle. A face-seal refers to a system whereby the barrier to air and water infiltration is the exterior face of the cladding. A rain screen provides a pressure-equalized and drained space between the cladding and the air and water sealed backup wall. The cladding in a rain screen is not necessarily water tight.

2.3.1 The Rain Screen Principle

The pressure-equalized space behind the cladding serves to interrupt the forces that cause rain penetration (See Figure 4, page 10). This concept is not new since it has been used in masonry cavity wall assemblies for at least one hundred years. Only within the last 35 years has this concept been used with other assemblies, most notably in the curtain wall industry. The rain screen system is technologically superior to the face seal system since the forces for water infiltration are negated and the seal of the building is protected from the weather and ultra-violet light. Unfortunately, the success of a rain screen is very dependant upon proper design, construction and maintenance. Figure 5 illustrates some of the mechanisms that can transport water across a rain screen cavity.



Water Transport Mechanisms

Figure 5

The integrity of the air barrier and provision of drainage is crucial. If deficiencies occur, the corrective work is often very difficult and expensive. When there are problems within the system, they are not necessarily evident until considerable damage has already been done.

2.3.2 The Face-Sealed System

Face-sealed systems are still quite common and are most frequently used when a monolithic cladding material, such as stucco or precast concrete, is employed. This system requires constant maintenance since the outer seal is subjected to the deleterious effects of weather, extreme temperature differences and ultra-violet light. By definition, however, problems with a face-sealed system are usually evident on the surface and are easily accessed and repaired.

2.4 Joint Design

Very few problems are normally encountered with moisture or air infiltration through the main component parts of a wall assembly because the nature of the materials is well understood, even by the most naive. No one, for instance, would clad a building in gypsum board and expect it to withstand the weather. Problems almost always arise at the connections between components (See *Look at Joint Performance*, CBD 97, G.K. Garden). Even the smallest opening can contribute an astonishing amount of air leakage. Consider a 3mm (1/8") gap all around the frame of a 900 x 1800mm (3'x6') window - this is equivalent to an 127mm (5") square opening, or a hole in your building envelope large enough to put your fist through.

Connections are usually caulked, gasketed or have a membrane applied over them. The most common connection is the caulked joint and it is also the most prone to failure. Selection and application of the appropriate sealant is critical (*See Use of Sealants*, CBD 96, G.K. Garden). Remember that these connections exist not only between fixed elements, but between operable elements such as windows and doors (weatherstripping). Considerations that need to be taken into account when selecting a sealing material and designing a connection include:

1. Amount of movement expected, either due to structural movement or temperature.

2. Size of gap between components.

3. Weather exposure.

4. Pressure differences across the joint.

5. Compatibility of materials.

6. Method of attachment and surface preparation.

7. Maintenance - Acceptable frequency and accessibility.

Most joints or connections in the envelope assembly are subject to some kind of movement, which implies that the sealing material must be elastic or have sufficient slack to accept that movement. Contrary to intuition, problems attributable to gap size usually occur because the gap is too small in proportion to the movement that occurs across it. For example, given a gap of 1mm in one instance and 6mm in another, a movement of plus or minus 1mm would require the sealing material to expand or compress 100% of its width in the first case and only 17% in the second (See *Joint Movement and Sealant Selection*, CBD 155, G.O.Handegord).

Considerable pressure differences can exist across a joint. If that joint is exposed to the weather, the chances of air and moisture infiltration are greatly amplified. A rain screen wall affords greater protection to their joint seals as they are shielded from the weather.

Most sealing materials rely on adhesive properties for attachment to the substrate. Adhesion relies on the compatibility of the components and in many cases requires the surfaces to be properly cleaned and primed. Many well designed joints have failed simply because the substrate was not properly prepared.

An inexpensive sealant may be employed if the building owner is prepared to provide more frequent maintenance. Where the seals are inaccessible, such as in a rain screen assembly, the use of anything less than premium quality materials and workmanship is pure folly.

2.5 The Building Code

The preface to the National Building Code of Canada 1990 (NBC 1990) states:

"The NBC is essentially a code of minimum regulations for public health, fire safety and structural sufficiency with respect to the public interest. . . . The content of the NBC pertains primarily to the need of health and safety. Requirements unrelated to health and safety are kept to a minimum; . . ."

Apart from Part 9, there is no requirement for a building to be insulated. Part 5 of the code requires that vapour diffusion, air leakage and rain penetration be "controlled" and Part 6 requires that heating be provided to "good engineering practice". Part 9 refers to buildings three stories in height or less and as such does not apply to medium and high rise apartment buildings. Section 9.25 refers to buildings of residential occupancy only and Article 9.25.2.1 requires "... sufficient thermal insulation to prevent moisture condensation ... during the winter and to ensure comfortable conditions for the occupants." Appendix notes A-9.25, A-9.25.2, A-9.25.6.2 and A-9.25.6.3 offer good discussions on air and vapour barriers. Unfortunately they are included for explanatory purposes only and do not form part of the requirements. Although these discussions are very informative, the effect of high thermal resistance values of an assembly is not highlighted. As discussed in 2.2 above, the integrity of the air barrier is extremely important in a highly insulated assembly since there will certainly be some surfaces inside the assembly at a temperature below the dew point.

Parts 5 and 6 have few changes from the 1985 edition. Prior to 1985 there was no mention of air barriers.

The Alberta Building Code (A.B.C.) is based upon the National Building Code (NBC) and, at the time of writing, the 1990 edition is about to be released. The 1985 edition has no requirement for buildings over three storeys to be insulated and, in discussion with Alberta Labour, Building Standards Branch officials, the 1990 edition will be unchanged in that regard. There will be some minor additions to the air barrier requirements over that stipulated in the NBC. There are no standards for air barriers as yet and the code still makes reference to polyethylene film. A large portion of the building science community is of the opinion that

"poly" is incapable of performing this function. Part 9 (1985) does have minimum thermal resistance values specified for residential buildings 3 storeys and less.

The requirements for control of vapour transmission, air leakage and rain penetration contained in Part 5 are quite general in nature and are predicated on the prevention of condensation on, or in, the assembly. It is possible to meet the requirements of the code by constructing a totally uninsulated building provided enough heat is supplied to prevent such condensation.

As can be seen in the argument presented above, it is possible to construct a building that "meets code" but would hardly be considered a "good building".

2.6 Technical Reports and Studies

The bibliography, which can be found in Appendix B, has been shortened to only include data applicable to those types of assemblies found on residential buildings in Alberta. A more comprehensive bibliography can be referenced in the publication entitled, *A Study of Cladding on Public Buildings*, produced by Morrison Hershfield for Public Works Canada.

The National Research Council of Canada is recognized world wide, as one of the leading authorities on the construction of buildings in a cold climate. The list of research programs and publications is too numerous to detail. If just the recommendations contained in the Canadian Building Digest (CBD) Reports (some 250 in all) were followed, there would be far fewer building envelope failures experienced. It is interesting to note that CBD-1 through CBD-170 were published prior to the energy crisis of the late 1970's.

The most significant recent research effort and one which is particularly relevant to the inventory of medium rise and high rise residential stock in Alberta, is the *CMHC Seminar on Brick Veneer Wall Systems*. This 1989 report describes a survey of buildings across Canada, a review of design methods and fundamental testing of the behaviour of this type of wall system.

The significant conclusions reached are summarized as follows:

- air leakage is a significant cause of moisture related problems
- corrosion resistance of ties, anchors and shelf angles is often inadequate
- poor construction practices are predominant and have resulted in much of the observed damage.

3.0 THE ALBERTA CONTEXT

3.1 The Alberta Climate

The climatic regions of Canada are described by Hare and Thomas, *Climates in Canada.* The Prairie Region is of particular interest for purposes of this report.

The prairie region climate is truly continental. It prevails over a vast area of interior Canada,

> ". . . extending from Lake of the Woods on the Ontario border more than 1600 km west and northwestward across Manitoba, Saskatchewan, and Alberta, to the foothills of the Western Cordilleras . . ."

Temperature changes from summer to winter are greater on the Prairies than in any other parts of Canada.

> "The extreme temperature range over the year throughout the entire region is from winter minimums colder than -40^{o}C to summertime maximums near or over 38^{o}C . . . The variations of precipitation throughout the year are typically continental, with moderately heavy falls during the summer, even by continental humid climate standards, with very light falls in the winter months . . .
>
> Thunderstorms are reported on average of 20 days each year throughout the area and practically all of these occur in the summer months . . . Hail storms can be particularly damaging to agriculture and buildings . . ."

The climate of Alberta is variable and extreme. Understanding the predominant patterns of temperature, wind, solar energy and precipitation over the seasons is critical for the proper design, construction and maintenance of exterior claddings and wall systems. Figure 6 lists climatic data, obtained from the Alberta Building Code, for the six communities included in our survey.

	Jan 1%	July Temp. DRY deg. C	July Temp. WET deg. C	Below 18 C Deg. Day	15 min. Rain (mm)	1 Day Rain (mm)	Total Precip. (mm)	Hourly Wind q 1/10 KPa	Elev. (m)	Long. deg, min	Lat. deg, min	Ground Snow (KPa)
Grande Prairie Airport	-39	27	18	6136	23	78	453	0.37	669	118 53'	55 11'	1.9
Edmonton Muni. Airport	-34	28	19	5782	23	114	488	0.32	671	113 31'	53 34'	1.6
Red Deer Airport	-35	29	18	5933	23	154	498	0.31	905	113 54'	52 11'	1.6
Calgary Int'l. Airport	-33	29	17	5321	23	95	437	0.4	1084	114 01'	51 06'	1.1
Lethbridge CDA	-33	31	18	4787	20	93	418	0.64	899	112 47'	49 42'	1.7
Peace River	-40	27	18	6469	15	48	375	0.24	571	117 26'	56 14'	2.4

PEACE RIVER - coldest both Jan. 1% and Degree Days; greatest snow load
- least amount of rainfall and lowest wind loads

LETHBRIDGE - significantly highest wind load

Climatic Data
Figure 6

The most severe winter climate is in the city of Peace River where degree days below 18^{o} C total 6,469, almost 700 greater than in Edmonton and 1,700 greater than the mildest climate in Lethbridge. Peace River has the greatest ground snow load at 2.4 kPa, yet has the least amount of annual precipitation at 375 mm. Peace River has the lowest 1 in 10 hourly design wind pressure at 0.24 kPa. Lethbridge has the mildest climate but with a 0.64 kPa design wind pressure which is 60% higher than the next closest which is Calgary at 0.40 kPa.

Seasonal temperature differences in Alberta can exceed 70 C^{o}. Exterior components of a well insulated assembly must be capable of withstanding this large temperature swing. This factor, combined with high wind loads in some instances, requires considerable care and consideration in design, construction and maintenance if the envelope is to perform satisfactorily.

3.2 Historical Background

Prior to the First World War, only two medium rise apartment buildings had been constructed in Alberta. Le Marchand Mansion, located in Edmonton, is a four storey brick masonry structure and was one of the first 'luxury' apartment buildings in western Canada. The six storey Anderson Apartments, located in Calgary, was also constructed of brick masonry. Both buildings are still standing and have been designated historical structures by Alberta Culture. Le Marchand Mansion was gutted in 1979 and converted to 'upscale' retail and office use. The Anderson still functions as an apartment building and retains its period appearance.

In the period between the First World War and 1963, no apartment buildings higher than three storeys were constructed in Alberta. There was a flurry of construction in 1963 with at least three apartment towers, the Avord Arms, the Palisades and Rowen House, constructed in quick succession in Edmonton. These structures were the first in Canada to use steel stud infill wall assemblies. The exterior cladding was stucco. The structures are still functioning well, but have undergone some upgrading over the years, due to the outdated technology of the time.

For the next ten years, apartment construction continued at a slow but steady pace with the structures located primarily in Edmonton and Calgary. The assemblies used at this time were about evenly divided between steel stud backup and masonry (including some clay tile) backup walls.

In the early 1970's, with the advent of the energy crisis and the subsequent boom of the Alberta economy, apartment construction increased dramatically. The assemblies used were almost exclusively steel stud backup walls with about an equal mix of brick veneer, precast concrete panels and stucco being used as an exterior cladding. At that time, medium and high rise apartments began to be built in some of the smaller communities in Alberta. It was also at that time Alberta Mortgage and Housing Corporation (A.M.H.C.)[1] started constructing

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[1]Since this project was initiated, A.M.H.C. has been merged with Alberta Municipal Affairs; however, the report will continue to use the A.M.H.C. designation for convenience.

high rise senior citizens' accommodation.

With the recession of the Alberta economy in the early 1980's, privately developed apartment projects came to a standstill. A.M.H.C. continued with one or two seniors' projects each year. During this time, problems with the building envelopes of recently completed buildings became evident.

In the last two years, (1989,1990) a small resurgence in construction has occurred with at least three high rise projects in Edmonton under construction or recently completed. The most prevalent wall assembly now being used is the Exterior Insulation and Finish System (E.I.F.S.). For a discussion on E.I.F.S., see 4.4.3.4, Stucco.

4.0 THE BUILDING ENVELOPE FAILURE SURVEY

4.1 Data Collection

We have included 46 buildings in this study. The telephone survey was the source of information for 32 (70%) buildings, investigations previously performed by MH were the source for nine (20%) buildings and we investigated five (10%) directly as part of this study. (See Appendix A, Building Envelope Survey - Table 1.)

In addition to information on specific buildings, we interviewed designers, contractors, building owners and managers, and government agencies in order to obtain their impressions and opinions on the nature, extent and recommended remedial work for building envelope failures.

4.1.1 Investigations

On-site investigations of five apartment buildings were conducted as part of this study. The results of those investigations are summarized in the Building Envelope Survey - Table 1, records 1 through 5. Buildings 1 and 2 are both located in Calgary; the remaining three buildings are located in Edmonton.

The field survey of the five buildings followed a similar procedure in each case. The property managers or resident managers were initially contacted by telephone to notify them of our survey objectives and to arrange a site visit. Prior to the site visits being made, each person contacted was asked to assemble any relevant documentation he or she might have available; such as construction drawings and specifications, previous consultants reports or studies, and any record of pertinent deficient items regarding the building exterior envelope. Of the five buildings visited, construction documents and drawings were only available for review at Buildings 1, 2 and 5.

During each interview the managers were asked to relate as much first hand knowledge of any building envelope concerns or complaints regarding their buildings, such as:

- complaints of occupant discomfort due to suites being too cold or too hot,
- evidence of water penetration or accumulation,
- poor window performance,
- staining on exterior finishes,
- evidence of structural distress, etc.

Once the interviews were complete, the managers were asked to give the site inspector a tour of typical suites, with the emphasis being on those areas of the building which may have had a known problem documented. The interior review also provided the site inspector an opportunity to review typical conditions via an "up-close" look at specific features in each building.

During each site review the site inspector was given an opportunity to review the exterior envelope from inside, on top via the roof areas, and outside by walking around the site.

During the site review of each building, a standard checklist, which covered the majority of performance problems of known envelope systems, was utilized. In addition, a Building Data Sheet, which covered any basic information that was collected during the interviews and other observations made during the site reviews, was filled out for each building visited. (For sample forms see Appendix B)

A 35mm camera was used to record any unique observations made during the visits, as well as to provide a record of the typical features of each site.

In the case of Building 2 in Calgary, another consultant had been retained by the owner to conduct a comprehensive review of known building envelope deficiencies. Test openings made in the exterior envelope for that study were

made available for our review. In addition, a second interview with the consultant retained for the work was conducted in order to obtain information collected through his efforts.

4.1.2 Telephone Survey

The information obtained for specific buildings is summarized in the Building Envelope Survey - Table 1, building record numbers 6 through 37. As shown in the table, the respondents were able to provide very little technical wall assembly data.

4.1.3 Previous Investigations

Since its inception in 1946, Morrison Hershfield has conducted numerous building envelope investigations all across Canada. In recent years, reports were done on nine buildings in Alberta that fit the criteria of this study. The information obtained is summarized in building record numbers 38 through 46.

4.1.4 Interviews

Information obtained from the interviews is summarized under Section 4.5.

4.2 Data Organization and Assembly Definitions

(as recorded in Appendix A, Table 1 - Building Envelope Survey.)

4.2.1 General Information

Pertinent background data under the heading 'General Information' includes location, year of construction, height, owner, information source and the basic structural system.

4.2.2 **Wall Assembly**

The possible components of a wall assembly are many and varied; the interrelationships between them can be quite complicated and in many cases circular. Cause and effect cannot be simply stated because of their interdependence (see 5.1). An attempt was made to include specific problems in the table but this soon became unwieldy and it was decided to limit the information to generic assemblies and how they had performed or are performing.

The wall assembly was broken down into the following generic assemblies which are followed by sub-classifications :

1. Cladding - *brick veneer, precast concrete, stucco, other*. The exterior cladding of a building is defined in the 1985 National building code of Canada (NBC) as "...those components of a building which are exposed to outdoor environment and are intended to provide protection against wind, water or vapour." This definition implies that cladding is the brick veneer in a masonry wall, the exterior single wythe of precast, the sheet steel finish, or glazed portions of exterior walls. The cladding is undoubtedly the first line of defence against the exterior environment but its service life is very dependent on other elements of the wall such as the air barrier, vapour barrier, insulation, and interior panels. Its service life is also directly related to the indoor conditions of temperature, humidity, and pressure.

2. Backup Wall - *steel studs, masonry, other*. Masonry walls include concrete block and clay tile units. A stud wall assembly includes exterior sheathing, studs and interior finish. The purpose of a backup wall is to provide the structural support for the cladding, air barrier, insulation and vapour retardant (barrier).

3. Type of Seal - *face seal or rain screen.* Face seals and rain screens are defined and discussed in Section 2.3. In many cases it was not evident whether the design intent was to provide a face seal or rain screen, and the classification noted in Table 1 constitutes, in part, a 'best guess' decision.

4. Vapour Retardant (barrier) - *none, polyethylene film, other.*

5. Air Barrier - *none, membrane, other.* An air barrier may or may not be specified since the concept is relatively recent. 'None' indicates no air barrier specified. The air barrier membrane may consist of sheathing, trowelled on mastic, pressure sensitive or thermally applied modified asphalt membranes, "air-tight drywall", and sealants or gaskets used singly or in combination. It is also important to realize that other components of the assembly have to function as an air barrier, specifically windows, doors and other such openings. An air barrier membrane must be tightly sealed to these other components to ensure the assembly performs as intended.

6. Water Resistance - This category refers to the myriad of interrelated components that resist the infiltration of exterior moisture (ie: rain and snow). This not only includes obvious water resistant components such as cladding and windows listed elsewhere but also flashings, sealants and drainage. The individual components are not listed in Table 1; rather, it provides a rating of the system as a whole.

7. In Wall Insulation - *thickness, type and material.* In wall insulation refers to insulation located within the backup wall such as the stud space or block cores.

8. Exterior insulation - *thickness, type and material.* Exterior insulation refers to insulation applied to the outside face of the backup wall. This insulation may have the cladding applied directly to it, such as stucco (E.I.F System), or a ventilated gap may be provided between the insulation and the cladding such as in a brick veneer rain screen system.

9. Windows - *operation and frame.* Types of operation include fixed, slider, casement and awning windows. The most common type of frames are wood and extruded aluminum.

10. Balconies - *none, penetrates envelope.* A yes (Y) response to the heading 'penetrates envelope' indicates the balcony exists and the balcony slab is

continuous through the envelope. A no (N) response indicates that the balcony slab is discontinuous at the envelope seal.

11. Patio Doors - *operation.* Types of operation are sliders and hinged.

4.2.3 Quality of Design, Construction and Maintenance

There are four additional factors that have a strong bearing on the performance of the building envelope, namely:

1. Quality of Construction Documents - These documents include drawings and specifications and are the responsibility of the designer, normally an architect and his sub-consultants.

2. As-built Conformity to the Construction Documents - How well did the contractor execute the designer's intent.

3. Quality of Workmanship - Even if the contractor carried out the intent of the construction documents, problems may arise if the quality of workmanship is less than properly executed normal trade practice, provided of course that what is normal in that jurisdiction is in fact technically correct and competently executed.

4. Quality of Maintenance - Even the best designed and constructed buildings require a regularly scheduled maintenance program.

4.2.4 Cost of Repair

Obtaining meaningful costs of repair was very difficult without going into substantial detail. Information obtained by telephone interview was, by its nature, lacking in detail and little costing could be obtained. It was also difficult to establish a common basis upon which costs could be compared. There was insufficient data to make meaningful comparisons on the basis of components and it was decided that a per suite cost would be the best comparison since this most accurately reflects costs against revenue calculations.

The per suite calculation imposes a bias when trying to use these costs to reflect the severity of a certain situation. For instance, the cost to repair the failure of brick veneer in a localized area (ie: just one face of a building) may have a lower per suite cost than the replacement of all windows, but the brick veneer problem may have a greater impact upon the habitability and safety of the building.

The possible level of repair and its efficacy also varies widely. For example, a face sealed and poorly insulated precast clad building may only require caulking of the precast panel joints every four or five years. A rain screen brick veneer wall may require the brick veneer and insulation to be removed and replaced after repairs are made to the air barrier membrane. The result in the first case is a thermally inefficient assembly that requires ongoing maintenance. The second case results in a good assembly that should give many years of low maintenance and thermally efficient performance but at a much higher capital cost than the first.

4.3 Rating System

A rating system was developed that would reflect the occurrence and severity of the various types of envelope failures in walls.

4.3.1 Assembly Ratings

Initially a rating scale of one to ten was attempted, however this implied a higher level of confidence and accuracy than we felt the data obtained could support. The rating system finally employed is relatively simple and reflects both past and present performance. The ratings were reduced to three subjective classifications as follows:

1. Failed - In one or more of the following functions, the major components or the entire assembly;

    a) failed to provide a barrier between the indoor and outdoor environments so the indoor environment could not be maintained dry and within acceptable limits of temperature and humidity for its occupants,

b) deteriorated to the extent that structural integrity was compromised and safety a concern,

and/or

c) was aesthetically objectionable making suites unrentable.

2. Will Fail if not Repaired. - The problems are minor at present but will lead to failure as defined above, if not repaired (other than normal maintenance).

3. OK - No problems or only minor problems that can be addressed through normal maintenance.

This rating system was applied against the following generic assemblies and components:

1. Overall Rating - This is our subjective assessment of the overall performance of the building envelope assembly. Failure of any one particular component may or may not lead to an overall failure. A failed rating indicates that major envelope problems exist, or existed, and the habitability and/or safety is, or was, of serious concern.

2. Main Structure - A failed rating does not indicate a structural failure but indicates unexpected movements (such as deflection of slab edges) within the structure sufficient to cause unintended loads to be transferred to the envelope assemblies. It also indicates deterioration of the structure caused by nonstructural envelope problems.

3. Cladding - A failed rating indicates a condition that would require major repairs such as removal and replacement of a significant portion of the cladding. The failure modes of cladding materials are as varied as the materials themselves. For example, a brick cladding system, part of an exterior wall having air leakage deficiencies, may experience spalling, cracking or displacement from moisture absorption due to condensation of moisture in the cavities. Anchorage for precast concrete panels may fail

due to inadequate corrosion protection.

4. Backup Wall - The main function of the backup wall is to provide the structural support for other components of the wall assembly. A failed rating indicates failure of that structural support. We have not seen any instances where a backup wall has failed without corresponding failures occurring in other elements of the assembly. As a result, it is very difficult to determine if the backup wall failure is a cause or an effect of other problems. (see 5.1 below.)

5. Type of seal - No rating is provided since, for the purposes of this study, any failure of the seal is treated as a component part of the assembly (ie: failure of the joints in a face sealed precast clad system are regarded as a cladding failure.)

6. Vapour Barrier - A failed rating indicates no effective vapour barrier present.

7. Air Barrier - A failed rating indicates a significant infiltration or exfiltration of air through the envelope.

8. Water Resistance - A failed rating indicates a significant infiltration of water into the assembly or interior space.

9. In Wall Insulation - The designed thermal resistance rating (R- value in imperial measure and R.S.I. value in metric measure) may vary considerably depending upon the assemblies employed and whether energy conservation was considered important at the time of construction. A failed rating indicates the actual thermal resistance rating falls well below the design intent for a significant portion of the assembly.

10. Exterior Insulation - A failed rating is the same as 9 above.

11. Windows - A failed rating indicates a condition that would require the removal and replacement of a significant number of the window assemblies.

12. Balconies - A failed rating indicates significant penetration of air and water at the balcony slab penetration of the envelope.

13. Patio Doors - A failed rating indicates a condition that would require the removal and replacement of a significant number of the patio door assemblies.

4.3.2 Design, construction and Maintenance Ratings

The quality ratings of good, average, poor and unknown, are simple, very subjective and self-explanatory. The four factors against which these ratings are measured are:

1. Quality of Construction Documents - The rating is gauged against two components:

    a) Clarity and completeness of the details and specifications,

    b) Conformity to the recognized technical standards at the time of preparation.

2. As-built Conformity to the Construction Documents - The rating is a measure of how well the contractor executed the designer's intent.

3. Quality of Workmanship - The rating is a measure of how well the workmanship compares against normal trade practice.

4. Quality of Maintenance - The rating is a measure of how well the building is maintained.

4.4 Analysis of Data

4.4.1 Limitations and Biases of Data

Although there were 46 buildings included in this study, the quality and quantity of information varied widely and therefore the statistics derived have a fairly high

degree of uncertainty. The sample is also biased since the buildings investigated were selected primarily because they were demonstrating problems with the envelope. The telephone interviews provide a more representative sample and identified a smaller proportion of buildings as functioning poorly (47%). However, the respondents were somewhat reluctant to discuss their buildings and many respondents were also technically naive. Information from our previous investigation reports (9) and our investigations as part of this study (5) have the lowest degree of uncertainty. Of the nine previous reports, eight were investigated because of identified problems, seven of which were deemed serious. The one building (record #42) of this group in which building envelope problems were not a concern was investigated to provide a pre-purchase evaluation.

Although mentioned in Section 4.3.1 above, we note again the very subjective nature of the rating system. This rating system, in detail, may be open to many interpretations. However we feel that, in general, it conveys the overall quality and performance adequately for the purposes of this study.

4.4.2 General Descriptive Information

4.4.2.1 Overall Rating of the Envelope

Fifteen (33%) buildings were classified as failed, eleven (24%) will fail, eighteen (39%) OK and there was insufficient data for two (4%) buildings. In other words, 57% of the buildings in our survey exhibited major problems with the envelope. As discussed above, if just the interviews are considered, 47% of the buildings were classified as exhibiting major problems. It is our opinion that the data supports the conclusion that close to half of all high rise apartment buildings constructed in Alberta since the early 1960's are suffering or have suffered major envelope problems. (See 4.4.2.4, page 34, Height, for note regarding medium rise buildings.)

4.4.2.2 Location

Of the forty-six buildings included in this study, thirty-six (78%) are located in Edmonton, four (9%) in Calgary, three (6%) in Lethbridge and one each in Red Deer, Grande Prairie and Peace River. The climatic data

for each of these locations is listed in Figure 6, Page 19.

Although the sample is small , it is interesting to note that one of the few buildings noted as being good (building number 6) is located in Peace River. There are other factors involved, but one can safely assume that one of the reasons for the good performance of this structure is due in part to low precipitation and wind pressures. Conversely, the three buildings located in Lethbridge (buildings 9, 10 and 11), all reported problems with water penetration at windows and caulked joints. This water penetration is undoubtedly related to the high wind pressures experienced in this community, even though the amount of precipitation (418 mm) is not much greater than in Peace River.

4.4.2.3 Year of Construction

Seventeen (37%) of the buildings were constructed in the 1970's, fourteen (30%) in the 1980's and nine (20%) in the 1960's. The year of construction was unknown for six buildings. Of the 40 known buildings, 33% were constructed in the period between 1963 and 1973, while 65% were constructed in the period between 1975 and 1985. The survey population probably reflects quite well the actual proportion of buildings constructed during these time frames.

The failure rate for the periods 1963 to 1973, and 1975 to 1985, are both 38%. However, if the 'Will Fail' rating is included, the percentages are 46% and 57% respectively. Intuitively one would expect the older buildings to show a higher rate of failure. The higher rate for the 75-85 period can be explained by three factors:

1. The period between 1975 and 1985 was a 'boom' period in the Alberta economy. Skilled trades were difficult to obtain and quality of construction was not a concern since 'anything would sell'.

2. Energy efficiency was a major concern during this period. Insulation values were increased without due attention, by both the design profession and the construction industry, to the implications (see 5.3.1).

3. As mentioned earlier in this report, older buildings were deficient not in components but in thermal efficiency and comfort. Comfort is extremely subjective and was impossible to quantify for this report. Quantifying thermal efficiency would have required extensive investigations well beyond the scope of this study. The failure rate for the 1963 to 1973 period would probably be considerably higher if thermal efficiency and comfort were identifiable.

4.4.2.4 **Height**

The majority (61%) of the heights of the buildings in our sample population fall between 10 and 18 storeys. The tallest structure is 34 storeys. The only correlation found between height and overall building envelope performance was that the taller buildings seemed to perform better (except for windows - see 4.9). The number of buildings included in the sample population with heights in excess of eighteen storeys was quite small (six with only one failed rating). Although one should be careful with generalities, we would surmise that taller structures are normally intended for prestige accommodation and consequently, a significant portion of the normally higher budget is directed toward quality construction.

Only four (8%) buildings in our survey fell in the medium rise (four to six storeys) category. This sample is too small to support any definitive statements about envelope failures with respect to height and probably understates the actual percentage of the population.

4.4.2.5 Ownership

Thirty (67%) buildings in the survey population are privately held with 15 (33%) owned by Alberta Mortgage and Housing Corporation (A.M.H.C.). The remaining building is owned by Canada Mortgage and Housing Corporation (C.M.H.C.). Correlations between ownership and envelope problems cannot be made because of the limited data base as outlined in 4.4.1 above.

A.M.H.C. and C.M.H.C. personnel were extremely helpful and discussed primarily those buildings exhibiting problems. The failure rate (including 'will fail') for the A.M.H.C. owned buildings in our study is 69%, but this is misleading since we included only fifteen buildings out of a portfolio of more than forty. Assuming the buildings not discussed have no major envelope problems, the percentage of buildings exhibiting problems falls to below 25%. Also, it should be noted that A.M.H.C. has repossessed many buildings where the owners have defaulted on their mortgage. Understandably, these buildings have a poor record of maintenance.

4.4.2.6 Main Structure

Of the known main structural systems, almost all buildings are cast in place concrete, with only two steel structures and one each of masonry and precast concrete. The main structure is unknown in fifteen (33%) of the buildings. Only three buildings were identified as having structural problems that contribute directly to envelope problems.

4.4.3 Cladding

The most prevalent cladding material in our sample population is brick veneer with seventeen (37%) instances. There are twelve (26%) precast clad buildings and ten (21%) finished with stucco. Five (11%) buildings are clad with metal wall panels and one building has a concrete block veneer. The sample population seems to reflect quite closely actual usage as known from general observation and broad experience.

The popularity or 'fashion' of a particular cladding can be seen by comparing the years of construction. The incidence of stucco cladding is spread fairly evenly over the 27 year span of our study and probably reflects a choice based upon economics. (A current increase in the use of stucco in E.I.F. systems is not reflected in the sample population.) 73% of precast clad buildings were constructed in the eight year period from 1972 to 1979, while 61% of the brick clad buildings were constructed in the eight year period from 1978 to 1985.

For the seventeen brick clad structures in the study, seven (41%) were deemed to have failed cladding, four (24%) will fail and six (35%) were OK. In terms of the overall envelope rating of those buildings clad with brick, eight (47%) failed, three (18%) will fail and six (35%) were OK.

The ten stucco clad buildings had the same rating for both the stucco and the overall envelope, namely four (40%) failed, two (20%) will fail and three (30%) OK. For one building the condition of the stucco was unknown.

The twelve precast clad buildings fared better with only one (8%) failed, seven (58%) will fail and four (33%) OK. Most of those buildings in the 'will fail' category require repairs to the face seal caulking which is a relatively minor problem. The overall envelope rating for precast clad structures is four (33%) failed, two (17%) will fail and six (50%) OK.

There are five buildings clad with metal panels and all are rated as OK. Building number 5 has brick and metal cladding and the failed rating only refers to the brick. No problems were identified with the metal cladding. Buildings number 7 and 32 had major problems with stucco and brick veneer respectively, and a metal cladding was installed as a retrofit, which seems to have corrected the problem.

Of those buildings with an overall envelope rating of OK, 100% of the metal clad buildings and 50% of the precast clad structures are rated as OK, while stucco and brick are essentially the same with OK ratings of 30% and 35%, respectively.

4.4.3.1 Metal Claddings

All five instances of metal cladding in our survey are of commercial quality and should not be confused with residential metal siding. Commercial metal cladding is identifiable by its deep profile (25mm to 75mm) and is almost always installed on subgirts to provide a rain screen. Although the success rate is high, this material suffers aesthetically from its association with industrial structures.

The high success rate for metal clad buildings is probably due to a number of factors. Metal is resistant to corrosion, provided the protective coatings are intact, and it is not susceptible to freeze-thaw damage. Commercial metal claddings have been traditionally installed following the rain screen principle and the panels are light thus reducing the size of the structural support penetrations (and subsequent thermal bridges) through the building seal.

4.4.3.2 Precast Concrete

We suspect the reason for the relatively high success rate of precast cladding is that it is normally a large monolithic panel which stands up well to weathering and has few joints. The most common problem encountered in our survey was failed caulking in the primary joints between the large main components. Most of the precast systems in our survey are face sealed (82%) and failure of the caulking can lead to air leakage and water infiltration. Although a constant maintenance problem, failed caulking can be readily identified and is relatively easy to repair.

The single most serious problem that can be expected with a precast system is the failure of panel anchorage. Failure of anchorage can usually be attributed to corrosion due to the combination of moisture within the assembly and inadequate corrosion protection of the steel anchors. Corrosion is a slow process and may not be evident for 20 years or more. The condition of the panel anchorage is difficult to ascertain unless there is evidence of rust stains or movement, or some panels are removed for inspection. There is no evidence of panel movement in the buildings

actually inspected but that does not mean anchorage deterioration is not taking place. As mentioned earlier, most of the precast clad buildings in our survey were built in the period 1972 to 1979. If there are anchorage problems they should soon become evident.

4.4.3.3 Masonry Veneer

Masonry veneer, which includes both brick and concrete block masonry units, is composed of many small elements, is highly labour intensive and must be detailed and constructed carefully if it is to perform well. An attempt was made to provide a rain screen in all masonry veneer buildings in our survey, with varying success.

Flashing stops short of exterior face of veneer,
no soft joint under veneer at support, thermal bridge at end of slab

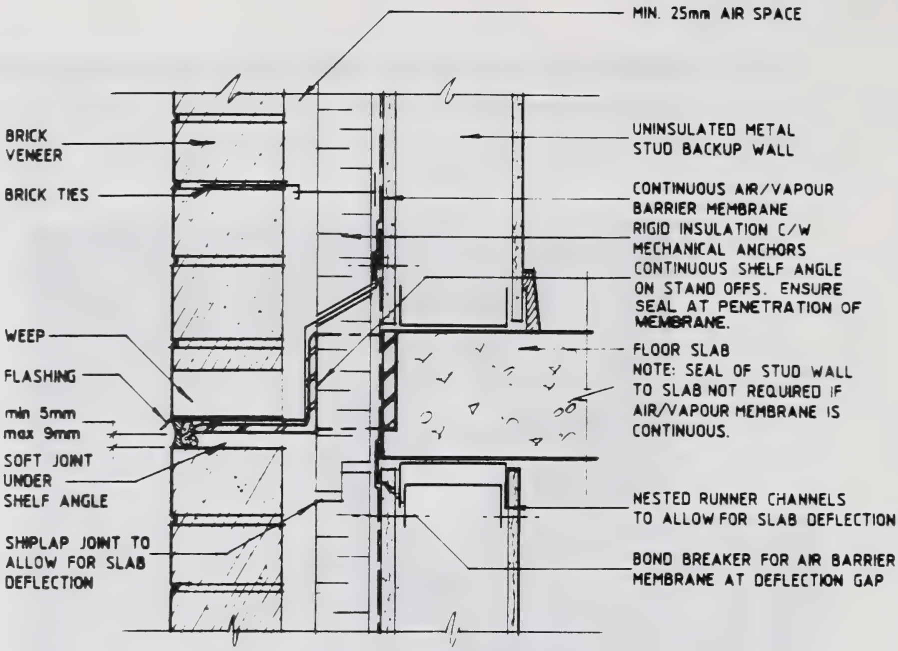
Block Veneer Photograph
Figure 7

The most common problem encountered was the lack of soft joints at the underside of the veneer support angles. This soft joint is required to accept the differential movement that occurs when the brick expands and the floor slabs deflect or the concrete frame shrinks as a result of creep . The photographs in Figures 7 and 8 are examples of typical problems

found. Figure 9 illustrates a suggested masonry shelf angle detail, including measures necessary to allow for creep and deflections. (See 4.4.12, Cost of Repair, for a discussion of these figures.)

Mortar droppings behind veneer, flashing stops short of exterior face of veneer, no soft joint under veneer at support

Brick Veneer Photograph
Figure 8



Suggested Masonry Veneer Detail
Figure 9

(Refer to the C.M.H.C. publication *Seminar on Brick Veneer Wall Systems*, Drysdale, Keller et al).

4.4.3.4 Stucco

A typical stucco clad wall assembly, listed from the exterior, would include; stucco, metal lath, building paper, exterior gypsum board, steel studs, glass fibre batt insulation, poly vapour barrier and interior gypsum board. Stucco is most commonly applied as a face-sealed system and suffers from the fact that it is a hard inflexible material subject to cracking. Cracking can be caused by shrinkage in the stucco or movements in the supporting structure. This is the main problem with stucco systems which was identified in our survey. The judicious placement of control and expansion joints is absolutely critical if the face seal is to be maintained.

The advent of 'acrylic ' stucco has improved the performance of stucco systems considerably because of its increased flexibility. However, the additional cost removes it from the 'economical' classification. Acrylic stuccos are the usual coating for most Exterior Insulation and Finishing Systems (E.I.F.S.).

E.I.F. Systems differ from normal stucco applications in that the acrylic stucco is applied directly to a continuous layer of rigid insulation (usually 25mm to 100mm of foam) over the exterior sheathing. The supporting stud wall may, or may not, be insulated. Thermal bridging at stud locations is reduced or eliminated with this system. As this is a relatively new assembly, the long term performance has not been verified. We have seen at least one instance where condensation on the interior face of the exterior sheathing has lead to the failure of the assembly. This instance was noted in a building other than an apartment and therefore is not noted in our survey.

Rain screen principles can be applied to stucco clad walls as well. A ventilated and drained air space can be provided behind the stucco by applying the stucco assembly to girts supported off the backup wall. No examples of this approach were noted in our survey.

4.4.4 Backup Wall

At 74%, steel stud assemblies are by far the most prevalent in our survey. No backup wall assemblies were rated as failed and only three (7%) were rated as will fail. The backup wall assembly for nine (19%) buildings was unknown.

Very few problems were identified with backup wall assemblies in our survey. Those that were could be directly attributable to moisture accumulation in the stud space leading to corrosion of the metal stud.

The C.M.H.C. publication *Seminar on Brick Veneer Wall Systems*, (Drysdale, Keller et al) has a good discussion of metal stud backup wall assemblies.

4.4.5 Type of Seal

There are sixteen face sealed buildings, nineteen rainscreen systems and fourteen buildings with an unknown type of seal. (Three buildings have both face seal and rain screen systems employed). In terms of the overall building rating both systems have a failed rating greater than 50%.

Although the rain screen is technologically superior to the face seal, as discussed earlier, the drawback to this system, and a possible explanation of our survey results, is that the success of a rain screen is very dependant upon proper design, construction and maintenance. An understanding of how and why a rain screen works is very important when maintenance and/or repairs are undertaken. In many instances the weep holes, which are a critical part of the necessary drainage requirement in a brick veneer system, have been sealed with caulking.

The disadvantage of a face seal is that the seal is usually dependant upon exposed caulked joints which require constant maintenance. This is the single most common problem identified in our survey with face sealed, precast concrete clad assemblies.

4.4.6 Air and Vapour Seal

Most telephone respondents were unable to identify the method of air and vapour seal employed on their buildings. It is also difficult, in many instances where seal problems are evident, to determine if the problem originates with the air or vapour seal. It is now well known that air leakage contributes far more to moisture accumulation within an assembly than does vapour transmission.

Where the information was known, all except two buildings, had a polyethylene vapour barrier specified. In our survey, vapour retardant problems were noted only where it was clear vapour transmission played a significant part in the failure. Accordingly, only three buildings were identified as having a failed vapour retardant and only one having a 'will fail' rating. It is interesting to note that all vapour retardant problems had a concomitant failed air barrier.

There was only one building where an air barrier membrane (apart from poly)

was specified; building 23, which is of recent construction. Even after the concept of an air barrier became relatively well known, many designers relied on the polyethylene vapour retarder to provide the air barrier. Poly is, in fact, a good air barrier provided it is well supported and the perimeter is well sealed. The problem is, in 'normal' construction procedures, the support and seal are not provided.

In our survey, eleven buildings were identified as having failed air barriers and each had an overall building rating of failed or will fail. In the nine previous building investigations (records 38 to 46), seven were identified as having a failed air barrier.

An example of the consequences of excessive air leakage is shown in Figure 10. This photo (not one of the surveyed buildings) shows moisture and ice buildup at the connection between the windows and precast wall panels, and efflorescence on the brick.

Consequences of Air Leakage
Figure 10

Although control of air flow was discussed earlier in this document, we reiterate it here because of its utmost importance.

The building science community is unanimous in its opinion that the largest single problem with *well insulated* building envelopes is the integrity of the air barrier system. The emphasis is on 'well insulated' since, in such an assembly, it is certain the surface temperature of some portion of the components will be below the dew point. If there is moisture laden air moving past such a surface, condensation is certain to occur. The antithesis of this occurs when little or no insulation exists in the assembly. The components of this type of assembly are normally quite warm and the chances of condensation occurring inside the assembly are quite low. In fact, the more air is allowed to flow out through the assembly, the greater the temperature regime of the wall. This allows whatever moisture that does accumulate to dry out. This is definitely the case for buildings 1, 38, and 42 and a contributing factor in buildings 18 and 27.

4.4.7 **Water Resistance**

On first glance this category seems to have the most serious consequences but one must remember this is a combination of the water resistance of all the components (ie: failed face seals or leaking windows). Water infiltration may be a problem in its own right or may be the result of other problems (see 5.1). With few exceptions, buildings with an overall failed rating also show a problem with water infiltration.

4.4.8 **Insulation**

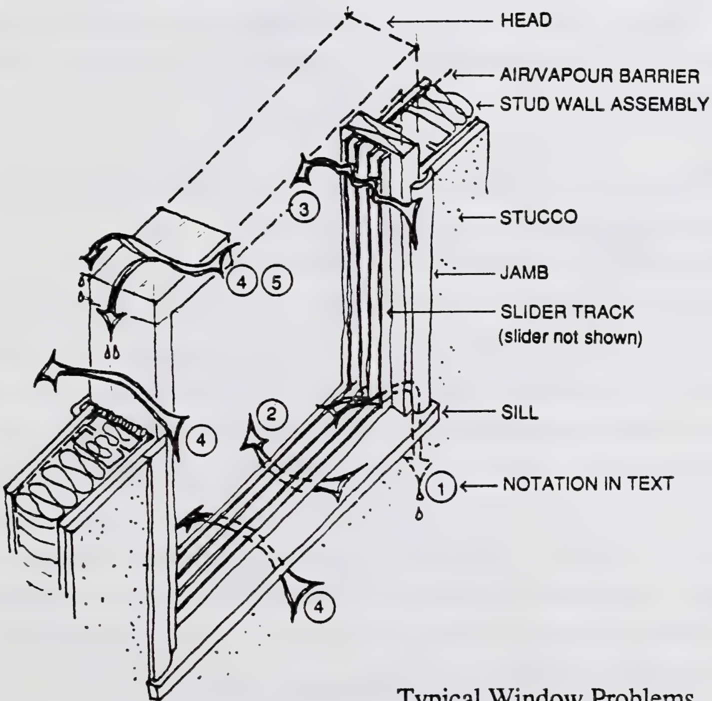
The most common method of insulating a wall system was, and still seems to be, glass fibre batts contained within the stud wall backup. This is the case for all known assemblies in our survey.

Insulation failures include insulation gaps, sags or settlement and insulation that has become wet. Although no insulation failures, with the exception of building #46, were noted in our survey, there is no doubt some buildings have insulation problems given the amount of water penetration noted.

4.4.9 **Windows**

Of the 46 buildings in our study, the condition of the windows was: unknown, eighteen (39%); nine (20%) OK; six (13%) will fail; 13 (28%) failed. Where the condition of the windows was known, 26% of those in buildings 12 storeys and less had a failed rating, while 69% of those in buildings over 12 storeys had failed ratings. The higher failure rate for tall structures can be explained by the greater pressures on the windows due to stack effect and increased wind loads.

Typical types of window problems identified in our survey are shown schematically in Figure 11. Because it has the worst record of performance, a horizontal slider in a single wythe stud wall is depicted. Other window and wall assembly combinations suffer similar problems but usually not to the same degree.



Typical Window Problems
Figure 11

Location 1 illustrates water infiltration at the sill/jamb connection, by far the most serious and common. The tracks become filled with water due to plugged or nonexistent drain holes and the poor seal at the junction of the sill and jamb allows the water to enter the assembly. This problem is usually due to a combination of low quality windows and poor maintenance.

Location 2 indicates a leaking seal between the window tracks, usually aluminum or vinyl, and the wood frame. It is almost always attributable to poor window quality.

Location 3 indicates a defective seal between the glass lights and the tracks or meeting styles. This can be caused by deflections due to structural strength insufficient to resist wind and stack pressure differences, worn weatherstripping or improperly installed sliders. We have seen many instances of sliders installed in an improper orientation.

Location 4 shows air infiltration between the window jamb and the wall framing. This can occur if a proper connection is not made between the frame and the air/vapour barrier.

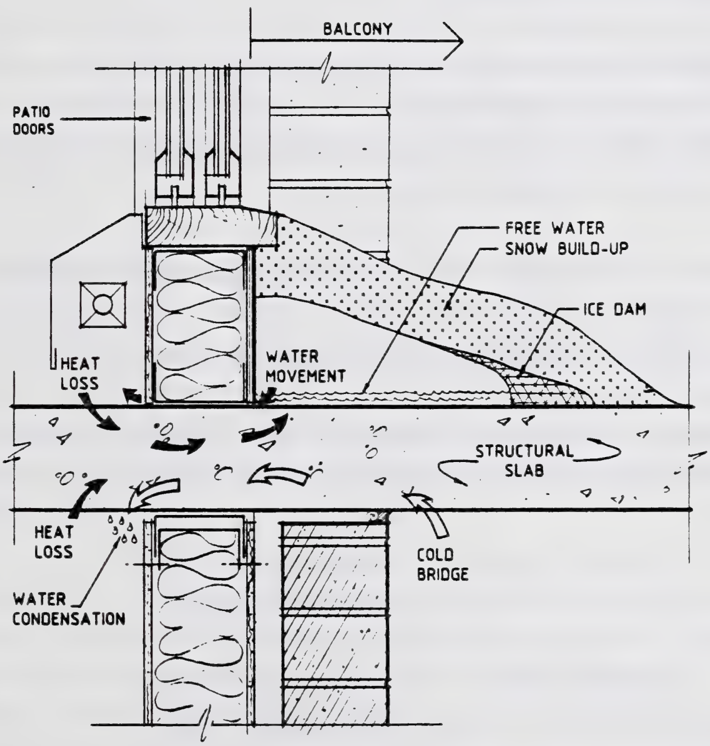
Location 5 shows water infiltration at the head of the window, which can occur if the head flashing is omitted or improperly installed.

A great deal of research and design effort has gone into the design of glazing systems (primarily curtain wall) for high rise office towers and it has become normal practice to incorporate quality windows in such a facility. Office towers windows are normally fixed but windows for residential accommodation are expected to be operable. Even though the performance requirements for operable windows are more stringent than fixed, high rise apartment buildings are still being constructed using low technology windows barely suitable for the single family home. In our study the overwhelming choice of windows is the aluminum horizontal slider, that choice is most probably based upon economics (false economics at that). There have been some recent improvements in horizontal sliders and, if kept small in size, they should perform adequately, however even these modestly improved windows are more expensive.

4.4.10 Balconies and Patio Doors

The discussion regarding aluminum horizontal sliding windows (above) pertains to patio doors as well. Patio doors do not normally have as many problems as windows. This can be explained by the fact the door is usually quite well protected by the balcony slab above. The most common mentioned problem with patio doors noted in our survey was weatherstripping. Only in two buildings, 21 and 35, had patio doors been replaced. Both buildings are over 20 years old and the original doors were low technology assemblies.

Complaints of water infiltration at the base of the wall adjoining the balcony were more numerous than complaints about patio doors (see Figure 12).



Balcony slab detail at Penetration of Envelope
Figure 12

Although there are only four instances where this problem is listed as serious in our survey table, there are many more that could be classed as inconveniences. This is an ongoing problem in building 28; thus when the developer decided to construct another identical building (#29), it was constructed with the balconies completely independent of the main structure. The second building has not experienced similar problems.

4.4.11 Quality of Design, Construction and Maintenance

This was the most difficult type of information to obtain and was not available through telephone interviews except for anecdotal remarks regarding building 36. We did obtain at least partial information on 16 of the buildings listed in Table 1 under the heading Quality.

We had contract documents available for buildings 1, 2, 5, 6 and 7 but conformity to those documents could only be determined for buildings 5 and 6. Information obtained from our previous reports, (buildings 38 to 46,) was limited since the drawings are no longer in our possession.

Where sufficient data exists, it is interesting to compare the overall building envelope rating (column two in Table 1) with the quality ratings. Following is a summary of the comparisons for buildings 1 through 6:

(Note that "overall quality" includes quality of construction documents, workmanship, maintenance and conformity of as-builts.)

Building Record 1	- overall rating - failed - workmanship - poor
Building Record 2	- overall rating - failed - workmanship - poor
Building Record 3	- overall rating - OK - overall quality - average or good

Building Record 4	- overall rating - OK - overall quality - average or good
Building Record 5	- overall rating - failed - technical design - poor (all others good)
Building Record 6	- overall rating - OK - overall quality - good
Building Record 7	- overall rating - failed - workmanship - poor

There is a strong one to one correspondence between the overall envelope rating and the quality ratings for the buildings listed above. Building #42, appears to contradict this correlation. However, good maintenance has overcome the deficiencies in design and construction to provide an adequately functioning building envelope but at some cost, as can be seen in the per suite cost of repair listed in Table 1.

4.4.12 **Cost of Repair**

There are 15 buildings in our survey with known repair costs or with sufficient information to estimate costs. The costs ranged from no expenditure required up to a maximum of $5,000 per suite. Two records indicate a range of costs. The low number is the cost to provide a minimal 'fix', and the high number is the cost to provide a 'like new' trouble free assembly.

For the purposes of cost comparisons, we chose the problems relating to masonry veneer shelf angles (see Figure 9, page 40). Buildings numbered 5, 24 and 38 all suffered shelf angle problems but as can be seen in Table 1 the costs are considerably different. For building 5, the problem is a lack of soft joints below the angle and can be resolved simply by cutting the mortar out from the joint below and applying a sealant. The cost for this portion of the repair is approximately $300.00 per suite. For building 24, the problem is further complicated by the fact the flashings and weeps above the shelf angle were incorrectly installed and the weeps plugged with mortar droppings. The repair

procedure necessitated the removal of three or four courses of brick above the shelf angle in addition to the provision of a soft joint under the angle (see Figure 8, page 39). The cost for this repair work is close to $1700.00 per suite. The last example, building 38, has a concrete block veneer supported not on a shelf angle, but on an extension of the floor slab. Deflection of the floor slab has transferred considerable load onto the veneer and the veneer has failed in many locations. Proper repair of this condition requires the complete removal and replacement of most, if not all, of the block work. The cost for this work would probably exceed $4,000.00 per suite. The slab extension is a very significant thermal bridge and source of water infiltration. It constitutes a problem in its own right (see Figure 7, page 38). The best solution in this case would be to redesign the entire cladding system so the end of the slab is inside the envelope.

It is very difficult to decide to what extent repair expenditures should be made. There are many economic factors to consider including amount of investment, value of the land, value of the building as it now stands, value of the building after repairs are made, yearly maintenance costs (including energy costs) expected in relation to the level of repairs made and, of course, rental market conditions. In the case of individual condominium ownership, the considerations become very complex. For example, one member of a condominium may have purchased a unit at the top of the market, while another may have purchased a unit when prices were low. Their reactions to major repairs, especially if the reserve funds are inadequate, will most likely be at odds with one another.

4.5 Interviews

A large number of groups and individuals within the Alberta building research, design, construction, maintenance and operations industries were contacted. The purpose was to gather facts and perspectives on wall envelope failures and causes.

Almost all individuals contacted were interested in this study and provided what information they could. The information obtained was general in nature since most individuals did not have specifics immediately available. Some costs of repair were obtained. However, the numbers are essentially meaningless without substantial backup information. It was very difficult to identify buildings with envelope problems because of an understandable concern that publication might

adversely affect property values.

In discussions with architects, engineers and government officials, it became evident that much more attention is being paid to building envelope design as a result of current problems. It is now becoming quite common to have an independent building envelope consultant employed on the project, both at the design stage and at the construction inspection stage (which is preferable to the litigation stage).

4.5.1 Alberta Mortgage and Housing Corporation

The largest single source of information was the Alberta Mortgage and Housing Corporation (A.M.H.C.). A.M.H.C.'s mandate is to provide affordable housing for Albertans and in this role owns or finances a very large portfolio. This portfolio includes more than 40 medium and high rise apartment buildings which are almost exclusively accommodation for senior citizens. The buildings are located in all the major centres in Alberta, range from one to 20 years old and are from six to 20 storeys in height. Only one high rise project is currently under construction and none in the design stage.

Property management and technical resource personnel in Edmonton, Calgary, Lethbridge, Red Deer, Grande Prairie and Fort McMurray were contacted. The persons contacted were very knowledgeable and contributed a substantial amount of technical information.

An internal decision was made in the 70's, to promote the use of brick veneer and steel stud wall (BV/SS) assemblies since it was determined this was the most economical from a life cycle costing point of view. The A.M.H.C. portfolio contains examples of many different assemblies but BV/SS is the most prevalent and has been, proportionally, the source of most of the problems. In spite of past problems, the Corporation is still convinced that BV/SS is the most cost effective system over the long term, provided it is constructed correctly.

The next most troublesome element of the envelope is windows. The problem of providing a proper seal is exacerbated by the necessity of ease of operation by seniors. Horizontal sliders, provided they are of a small size and good quality

construction, are the most economical choice, in their opinion. (For a discussion on windows see 4.4.9, page 45.)

Balcony related problems are not prevalent since A.M.H.C.'s policy is not to provide balconies for senior's accommodation.

No A.M.H.C. buildings are air-conditioned and almost all have pressurized corridors. An imbalance in pressurization has been suspected of contributing to building envelope failure in some cases. (For a discussion on building pressurization see 2.2.3, page 8.)

It is worth noting that A.M.H.C., a government agency, has a very elaborate design, specification and contract management procedure, yet they have experienced at least four major envelope failures. The comment "There is no substitute for a good, conscientious contractor" was heard more than once.

The number one reason given by A.M.H.C. for envelope problems in construction generally, is the failure of the designer to follow the basic principles of rain screen design and to ensure that the air barrier is intact. When A.M.H.C. engages an outside consultant A.M.H.C. provides the standards to be met. These standards are regularly updated in response to the problems previously experienced.

The second major source of problems is the quality of workmanship, which is very difficult to control on large projects with only biweekly inspections. Testing of assemblies is not employed unless a problem has been experienced. When a problem is discovered with the envelope (usually some years after completion) the first approach is to contact the original consultant. If the consultant is not responsive or is no longer in business, then the problem is looked at by in-house personnel. If that is not successful, an outside building envelope specialist is consulted.

Two structures, in particular, have experienced major envelope failures recently. Both buildings are high rises with BV/SS wall assemblies and the brick veneer was showing considerable signs of distress. One structure has a steel frame and the other a cast in place concrete frame. It was determined that the lack of soft

joints at the veneer support angles and blocked vent openings, due to mortar droppings in the cavity, were the sources of the problem. Repairs to one building were completed recently by removing some bricks and cleaning the cavity, stripping the mortar out from below the veneer support angle and caulking the gap. The repairs seem to have been successful and it is planned to perform similar remedial work on the second structure.

4.5.2 Canada Mortgage and Housing Corporation

Canada Mortgage and Housing Corporation (C.M.H.C.) was contacted, however, C.M.H.C. is now strictly a lending institution and has no portfolio. A discussion of a general nature with the Director of Technical Services centred around the problems with brick veneer and steel stud systems and windows.

C.M.H.C. promotes and provides financial support for research related to housing. It maintains a substantial list of technical publications which are available to the public. Many of these documents were of considerable assistance in the preparation of this study and are listed in the Bibliography.

4.5.3 Design Consultants

Most consultants contacted admitted they are paying more attention to envelope design than they had five or ten years ago. Many would not admit to any envelope failures on buildings they had designed. Some architects employ independent building envelope specialists at the working drawing stage, primarily on schools and other public works projects.

Frustration was expressed frequently with projects commissioned by private developers, for whom initial capital cost concerns override any consideration of the long term benefits of quality construction. In many instances, the developer prefers not to have the designer on site. This allows him more freedom (and cost control) in the construction of his building.

One architect mentioned that he has designed both simple and complicated wall systems and has had success and failures with both. In his opinion, success or failure is dependant upon the skill and ethics of the contractor.

4.5.4 Private Owners and Management Companies.

A number of private owners (including condominium associations) and management companies were contacted. The average portfolio was limited to only one or two apartment buildings and therefore discussions were directed at specific buildings. Most individuals had very limited technical knowledge of their buildings. The initial response to the question 'Do you have any building envelope problems with your buildings?' was almost always 'No'. Subsequent questions prompted replies such as:

> "There are some leaks around the windows in a driving rain storm, especially on the north-west corner."
>
> "Some of the brick looks loose at the top of the south wall."
>
> "We are recaulking all the joints in the concrete this year." (The building is clad in precast panels and there is evidence of moisture infiltration.)
>
> "We have leaks under some of the patio doors."

In the course of our conversations, it became clear this group has little understanding of the cause and effects of envelope failures. The Cause and Effect Chart (Figure 13, page 57) should help to improve that level of understanding.

4.5.5 Contractors

A few of the contractors contacted were more than willing to discuss their particular solutions to envelope problems. One contractor has devised a method of repair for horizontal sliding windows whereby the sill track is removed, a waterproof membrane installed and the track replaced.

A glazing contractor said the main problem with windows is the use of undersized (usually 3 mm) glass thickness for large windows, combined with unshimmed glazing tape. The undersized glass deflects under pressure (wind or stack effect) causing a pumping action on the glazing tape leading to loss of seal.

Another glazing contractor stated owners and managers seem to forget that windows and patio doors (especially weatherstripping) should be included in the maintenance procedures, not just roofs and exterior painting.

4.5.6 Insurance Companies

Building insurance policies do not cover building envelope failures unless caused by some outside force, such as a tornado or fire. The insurance companies contacted were unable to contribute any information to this study.

4.5.7 Legal Community

An attempt was made to research some of the envelope problems that have been before the courts. It was quickly evident this subject is very complicated and beyond the scope of this document.

Litigation is becoming much more prevalent in all business dealings and the construction industry is no exception. The legal relationship between the owner, consultants, contractor, and suppliers is a complicated one at best and, coupled with a building that fails to perform as expected, that relationship becomes very complicated indeed. This difficult situation is made even worse by the fact that most building envelope problems do not become apparent until several years after construction is completed. This time lag makes recourse through the courts very difficult, if not impossible.

5.0 CONCLUSIONS

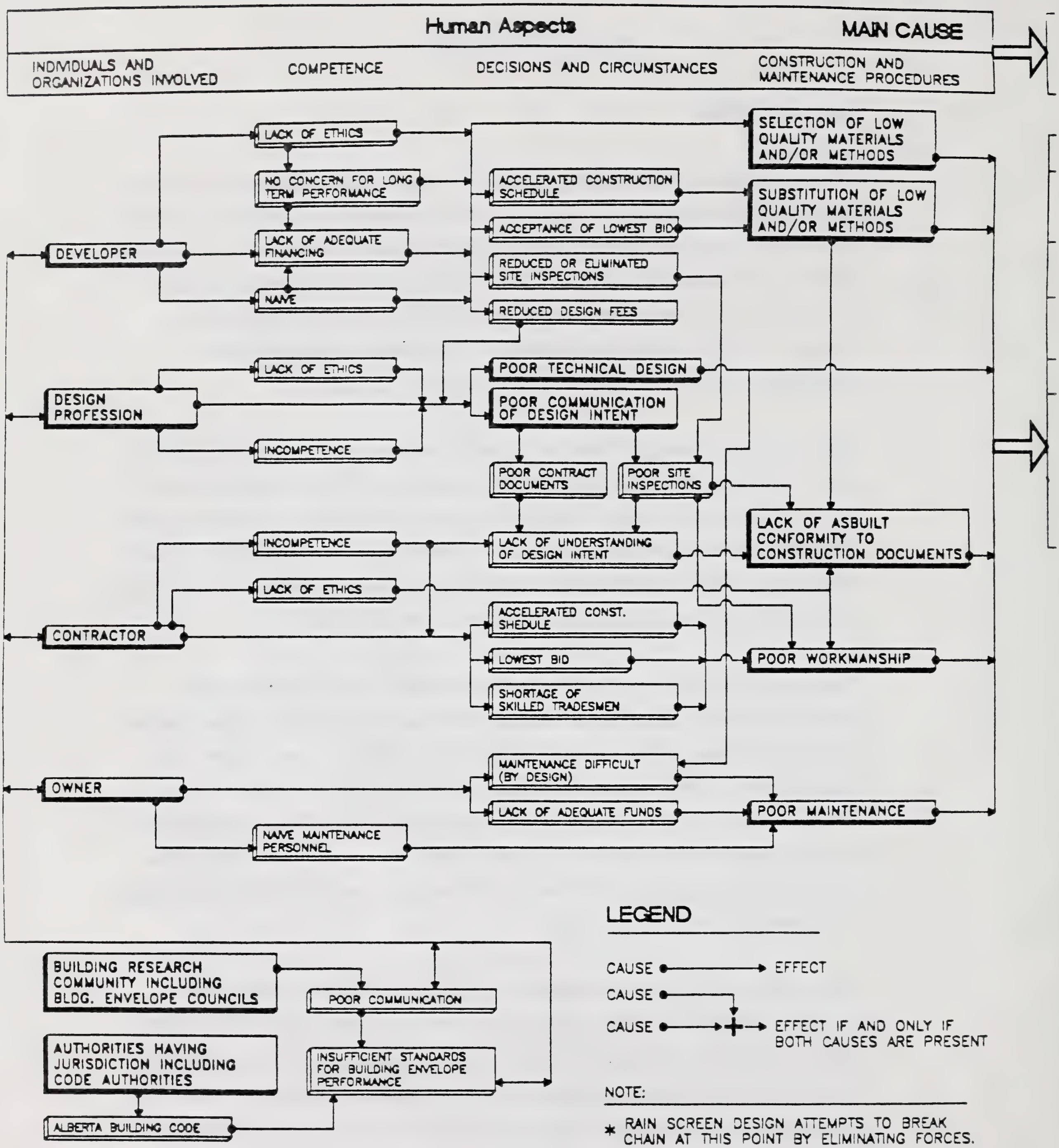
5.1 Cause and Effect

As discussed earlier, the building envelope must provide a comfortable, safe, and aesthetically acceptable environment for the occupants of the building. In order to accomplish this, the primary function of the envelope is to control air, moisture and heat movement through the assembly. When there is a failure in any one of these areas, a very complicated cause and effect interaction is almost always initiated. This cause and effect interaction is simplified and represented graphically in the Cause and Effect Chart, Figure 13, page 57.

Every building envelope failure can be traced back to an error or omission on the part of the people involved. (However one might say, "But buildings do wear out." This statement is true, although with proper maintenance a building can last for centuries - there are a many examples.) Accordingly, the chart has two main parts; the left side, titled Main Cause, addresses the human aspects of the problem and the right side, titled Main Effect, addresses the technical.

The nodes of the chart are connected with one way arrows. The bullet end signifies the cause and the arrow head signifies the effect. Any one node may be the cause of several effects and may in turn be the effect of several causes. A large plus sign indicates the effect can result if and only if both causal events occur in unison. It is important to note that the rain screen principle is intended to break the chain of cause and effect at one of these locations notated with a plus sign. By removing many of the forces contributing to water infiltration, openings in the cladding cause few problems.

It is possible to start at any one node and trace the lines back to determine possible causes and, conversely, trace them forward to determine possible effects. In many instances the routes are very circular indicating a feed-back mechanism (ie: moisture infiltration may cause structural damage to components, which in turn may cause an opening in the envelope which may lead to more moisture infiltration).



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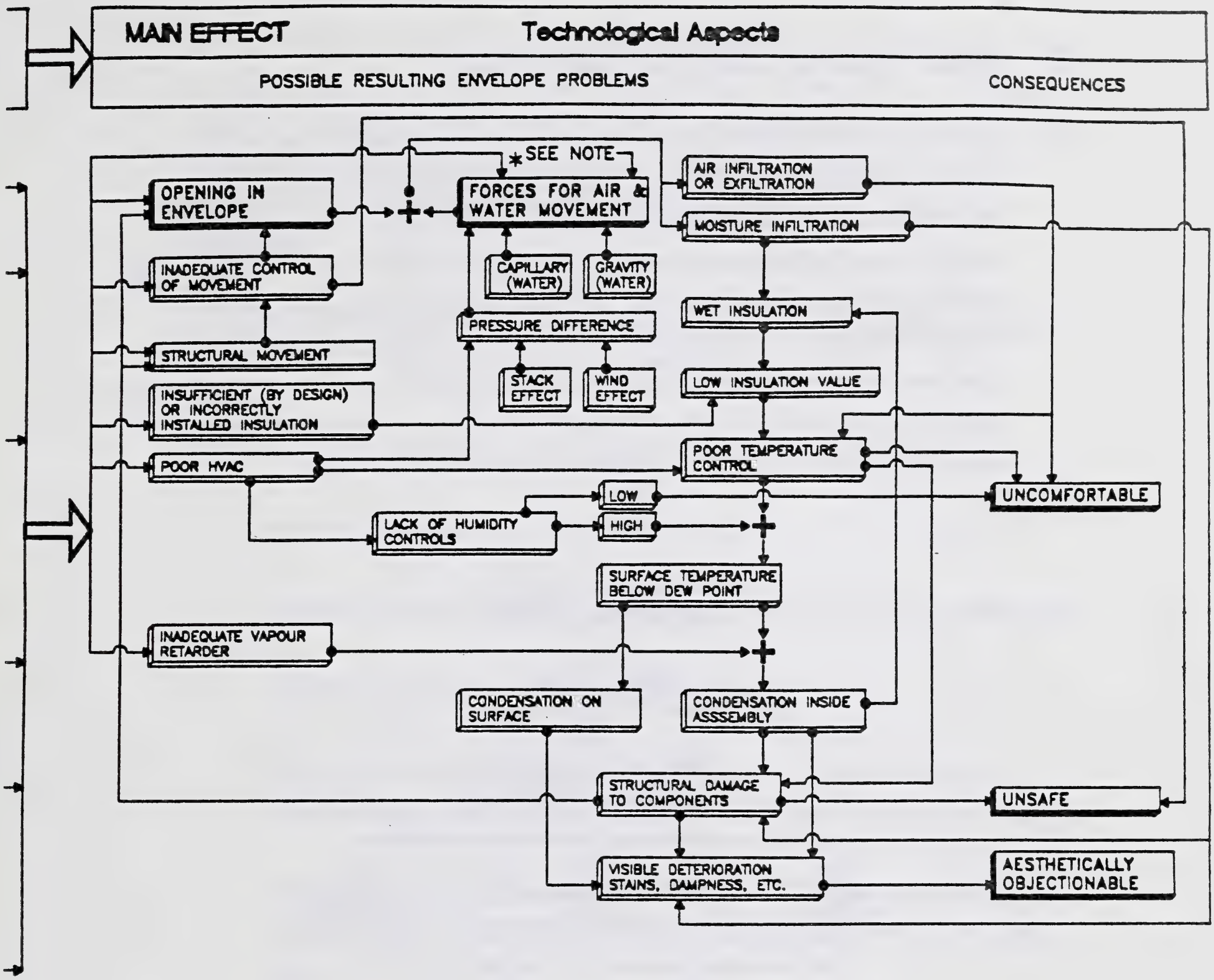


BUILDING ENVELOPE FAILURES

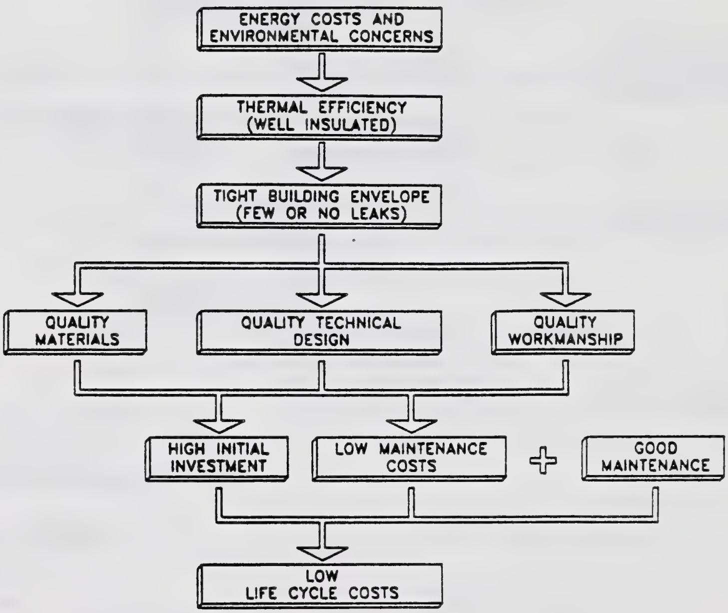
CAUSE AND EFFECT CHART

Figure 13

Morrison Hershfield Limited
Consulting Engineers

5.2 Primary Causes of Building Envelope Failures

On the human side of the equation, the single most common cause of failures in building envelopes is the failure to address the effects of providing a well insulated building. Once the decision is made to provide a thermally efficient assembly (predicated upon energy costs), there is no choice but to provide a tight building envelope (See Figure 14). As stated above, the effects of increased thermal resistance are well known to the building science community and there have been numerous studies and publications addressing the issue. There are only three possible reasons why the problem still persists; naivety, incompetence or a lack of ethics on the part of the people or organizations involved.



Energy Costs Implication Chart

Figure 14

On the technical side, the most common problem encountered in our survey is the deterioration of the assembly caused by water, the source of which is either rain infiltration or condensation. Although it is difficult in many instances to

differentiate between rain and condensation problems, we can confidently say that the main source of water infiltration is poor quality windows. This is followed closely by condensation due to air leakage. Improperly designed, installed and/or maintained caulked joints is also a major cause of air leakage and direct rain penetration. A contributing factor is lack of adequate drainage from the assemblies.

A common problem with brick veneer walls, which is unrelated to air and water tightness, is the lack of soft joints under veneer support angles.

In general, the most common cause of failure for the wall assembly are:

- Poor workmanship and/or lack of inspection.

- Ignorance of, or choosing to ignore, recognized standards of construction.

- Use of inappropriate or out-dated technology.

- Failure to take into account movement and deflections in the main structure due to wind and live loads, creep and broad temperature changes.

- Failure to take into account pressure differentials across the building envelope due to wind and aerodynamics, the H.V.A.C. system, and stack effect.

- Failure to take into account the high humidity conditions in residential buildings (as opposed to office buildings).

- Failure to take into account the major structural penetrations of the building envelope at balconies.

5.3 Technical Solutions

In our survey, all failures could have been avoided if basic principles (most, if not all, well known) had been followed. Technical solutions to the problems described in this survey can be found in references cited in the Bibliography.

6.0 RECOMMENDATIONS

6.1 Strategies for Avoidance

On the human side of the equation, there is no substitute for the proper selection of quality materials, good technical design or high quality, workmanship and maintenance. On the technical side, the most effective way to break the cause and effect chain is to attack the weakest links; that is at the point where two causes occurring simultaneously are required to result in an effect (the plus signs in the Cause and Effect Table).

As discussed above, one of the most effective methods to break the chain is to utilize the rain screen principle when constructing a wall assembly. In our survey, metal clad rain screens have been 100% successful, while brick veneer systems have demonstrated considerable problems. The disparity can be explained, not by problems in principle, but by the complexity and properties of brick systems. By its very nature, a rain screen is difficult to repair if not constructed correctly. This implies that quality design, construction and maintenance are required to ensure proper performance.

Following is a list of some specific recommendations:

- Provide a tight air and water building seal, especially at major junctions such as roof/wall connections and windows.

- Install insulation continuously on the outside of the structure.

- Install good quality windows. Can2 - A440 is a minimum performance specification for windows. It is our opinion that any windows installed in buildings over 3 storeys in height should be required, as a minimum, to meet the most restrictive requirements of that specification. For a list of tested window assemblies refer to Canadian Construction Materials Centre (CCMC) *Evaluations Listings*, published by the National Research Council of Canada.

- Provide drainage from wall cavities.

- Use flexible membranes with mechanical connections, as opposed to caulking, to seal joints.

- If caulking must be used, ensure the design of the joint is proper, the appropriate sealant is employed, the surfaces are compatible, clean and primed, and the installation done by a skilled tradesman.

6.2 Strategies for Repair

When repair work is being done, substandard materials should be replaced with high quality ones. It is our experience that the long term costs of a poor repair job will soon offset any savings in initial costs. It is important the individuals involved in the repair work understand the consequences of their actions. If a rain screen brick veneer wall is leaking, the source of the problem must be determined before repair work is undertaken. It may be that the brick veneer will have to be removed to solve the problem. If the correct solution is not determined, what started out as a minor problem may turn into a major problem if inappropriate measures (such as the caulking of weep holes) are attempted.

It is also important that problems are investigated as early as possible. What appears to be a minor problem, when first evident, may in fact have serious underlying causes. If corrected early, the repair procedures may be quite simple. If allowed to continue, the hidden deterioration may eventually require major repairs. The analogy with human cancer is not inappropriate.

6.3 Suggested Further Research

In reviewing the results of the survey and investigations carried out as part of this project, two significant observations can be made. The majority of the problems reported with exterior walls are related to water penetration and the majority of those are related to windows.

In recent years, air leakage in exterior wall assemblies has been the focus of much of the research effort. A great deal has been learned about rain screen wall performance, and the affect of air tightness on water penetration. There is still a great deal of research work to be done in these areas, some of which CMHC has

already initiated. Notably, compartmentalization, design detailing and structural aspects of air barrier systems are part of current CMHC research projects. In focusing on the water penetration problem, several opportunities for further research present themselves and are outlined below.

6.3.1 Flashing Technology

All aspects of gravity drainage of wall systems should be examined. Upon investigation of many water penetration problems it is discovered that missing window head flashings, improperly lapped flashing, discontinuous flashings or deteriorated flashings are the cause of the reported problem. In addition, capillary breaks and water drips are often dealt with poorly resulting in water running down the face of a building instead of falling away from the building. To a large extent, the materials and details currently used for flashing have remained unchanged for decades. As a result, designers are attempting to impose an old technology on new materials and wall systems.

6.3.2 Windows

Despite the fact that most windows used in todays buildings meet basic performance criteria of the CSA A440 standard, windows are still the primary source of problems in exterior walls. Many of the problems are related to the connections between windows and other wall components. A study of how these connections are detailed and actually constructed is definitely warranted. Furthermore, no information is currently available on how window units themselves perform once installed. That is, although a window meets a certain water penetration standard in the lab, how does it perform in the field after installation?

The basic design of many residential windows does not incorporate the basic rain screen design details which have been used with great success in the curtain wall industry. An investigation into why this has occurred and what is necessary to make changes to residential window technology would be very useful.

6.3.3 Exterior Insulation Finish Systems

EIFS walls are becoming increasingly popular throughout Canada. However, the way they are currently used fails to incorporate many of the basic requirements for rain screen walls. How durable are these wall systems? Will we be replacing most of these walls in 10 years? Some of the current wall assemblies using this system incorporate some questionable details. For example, it is likely that the gypsum sheathing, sandwiched between polystyrene insulation on the exterior and fibreglass insulation in the stud space, will become very moist. This will lead to loss of strength and in some cases failure of the gypsum sheathing which supports the EIFS. Although not represented in our surveyed buildings, we have been involved in at least one investigation where this is suspected to have occurred. At present little is known about the extent or magnitude of this problem.

6.4 A Measure of Building Quality

While writing this report, the statement "Caveat Emptor" ("Buyer Beware") kept jumping to mind. No protection exists for the individual who purchases a building in which he has had no direct involvement in the actual construction. The real estate industry has a rating system for commercial properties, but this system addresses property values calculated mainly on revenue expected. That revenue is based upon location and visual quality (eye appeal) of the building. As we have seen in this study, what meets the eye is not necessarily the true situation. We have also seen that conformance to legislated standards does not guarantee a good building. We would like to suggest a standard rating be established that would provide a common basis upon which the technical quality of buildings could be compared.

This rating system would be similar to a report card, with values and weights assigned to the many components of a building. The overall rating would be a weighted average. There is no doubt many of the ratings would be quite subjective, but with a comprehensive list of components and an assigned list of values of various typical assemblies, the subjective aspects could be substantially reduced. The ratings could be grouped under the quality headings discussed in this report: quality of materials; quality of technical design; as-built conformity; quality of workmanship; quality of maintenance.

We envisage this rating system as being administered by the Building Envelope Councils and applied by professionals within the building science and design fields. The building rating would require a professional seal. Building envelope investigations of existing buildings perform most of the tasks envisioned for this rating system. It would be a simple matter to apply the rating if the standards are made available. For new buildings, the professional responsible for the design of the building would assign the ratings. There is some problem with asking the designer to rate his own performance, however, if the standards are sufficiently clear this should be a minor problem. In fact, the standards could provide a good reference source for the designer.

The establishment of rating standards would be a daunting task. It would probably take several years and there would be endless arguments over the details. However, even if the rating system is less than perfect, we think it would still serve the building industry well. Almost any system would be preferable to "Caveat Emptor".

Building envelope design principles are not new. The recent increase in failures in the subject group of buildings could have been avoided if those basic design principles were followed. The design community now appears to be addressing those problems (albeit belatedly) but developers, the construction industry, maintenance personnel and owners are still somewhat naive. It is hoped that this document will assist in the understanding and avoidance of building envelope failures.

BIBLIOGRAPHY

GENERAL

Allen, D.E. and Dagliesh, W.A. 1973. Dynamic Wind Loads and Cladding Design. The Preliminary Publication of the IABSE Symposium on Resistance and Ultimate Deformability of Structures Acted on by Well Defined Repeated Loads, pp. 279-285.

Brown, W.P. and Wilson, A.G. 1963. Thermal Bridges in Buildings. Canadian Building Digest No. 44. Ottawa: National Research Council of Canada, Division of Building Research, 4 pp.

CIB/NBRI. 1967. CIB International Symposium on Weathertight Joints for Walls. CIB Report 11, NBRI Report 51C. Oslo: CIB/NBRI.

Dalgliesh, W.A. 1981. Wind Loads on Low Buildings. Building Practice Note No. 18, Ottawa: National Research Council of Canada, Division of Building Research, 7 pp.

Diliger, W.H. 1983. Effects of Temperature on Exterior Walls of a Highrise Building. Proceedings of the Second CSCE Conference on Building Science and Technology. Waterloo: University, pp. 97-125.

Division of Building Research. 1982. Exterior Walls: Understanding the Problems. Building Science Insight '82 Proceedings. Proceedings No. 6. Ottawa: National Research Council of Canada, Division of Building Research, 63 pp.

Division of Building Research. 1980. Construction Details for Airtightness. Proceedings No. 3. Ottawa: National Research Council of Canada, Division of Building Research, 58 pp.

Garden, G.K. 1965. Control of Air Leakage is Important. Canadian Building Digest No. 72. Ottawa: National Research Council of Canada, Division of Building Research, 4 pp.

Garden, G.K. 1963. Rain Penetration and Its Control. Canadian Building Digest No. 40. Ottawa: National Research Council of Canada, Division of Building Research, 4 pp.

Handegord, G.O.P. 1985. Design Principles Revisited - Through the Looking Glass. Proceedings of the Fourth Canadian Building Congress, pp 165-175.

Hutcheon, N.B. and Handegord, G.O.P. 1983. Building Science for a Cold Climate. Toronto: John Wiley & Sons, 440 pp.

Hutcheon, N.B. 1963. Requirements for Exterior Walls. Canadian Building Digest No. 49. Ottawa: National Research Council of Canada , Division of Building Research, 4pp.

Kerr, Dale D. 1985. Annotated Bibliography on the Rain Screen Principle. Bibliography No. 45. Ottawa: National Rain Screen Principle. Bibliography No. 45. Ottawa: National Research Council of Canada, Division of Building Research, 35 pp.

Lacy, R.E. Survey of Meteorological Information for Architecture and Building. Garston, UK: Building Research Station.

Latta, J.K. 1973. Walls, Windows and Roofs for the Canadian Climate. Special Technical Publication No. 1. Ottawa: National Research Council of Canada, Division of Building Research, 94 pp.

Pehnt, W., Editor. 1964. Encyclopedia of Modern Architecture. New York: H.N. Abrams, Inc.

Quirouette, R.L. 1985. The Difference Between a Vapour Barrier and an Air Barrier. Building Practice Note No. 54. Ottawa: National Research Council of Canada, Institute for Research in Construction, 13 pp.

RILEM/CIB. 1965. RILEM/CIB Symposium, Moisture Problems in Buildings.

Robinson, G. and Baker, M.C. 1975. Wind-Driven Rain and Buildings. Technical Research Paper No. 445. Ottawa: National Research Council of Canada, Division of Building Research, 19 pp.

Rousseau, M.Z. 1984. Sources of Moisture and Its Migration Through the Building Enclosure. ASTM Standardization News, Vol. 12, No. 11, November 1984, pp.35-37.

Shaw, C.Y. 1985. Air Leakage Tests on Polyethylene Membrane Installed in a Wood Frame Wall. Building Research Note No. 225. Ottawa: National Research Council of Canada, Division of Building Research.

Wilson, A.G. 1961. Air Leakage in Buildings. Canadian Building Digest No. 23. Ottawa: National Research Council of Canada, Division of Building Research, 4 pp.

MASONRY

1984. Brick Veneer: How Brick Veneer Performs on High-Rise Buildings. Construction Canada Magazine, Vol. 26, No. 3., May 1984.

American Society for Testing and Materials. 1985. Masonry: Research, Applicaton, and Problems. STP 871. Philadelphia: American Society for Testing and Materials.

Allen, D.E. 1978. Damage to Brick and Stone Veneer on Tall Buildings. Building Practice Note No. 7. Ottawa: National Research Council of Canada, Division of Building Research, 1 p.

Ashton, H.E. 1970. Coatings for Masonry Surfaces. Canadian Building Digest No. 131. Ottawa: National Research Council of Canada, Division of Building Research, 4pp.

Davison, J.I. 1980. Workmanship and Rain Penetration of Masonry Walls. Building Practice Note. No. 16. Ottawa: National Research Council of Canada, Division of Building Research, 6 pp.

Davison, J.I. 1979. Rain Penetration and Design Detail for Masonry Walls. Building Practice Note No. 13. Ottawa: National Research Council of Canada, Division of Building Research, 8 pp.

Dawe, J.L., Francis, R.M., and Valsangkar, A.J., Editors. 1986. Proceedings of Fourth Canadian Masonry Symposium. Fredericton: University of New Brunswick.

Grimm, C.T. 1984. Brick Veneer: A Second Opinion. The Construction Specifier, April.

Hatzinikolas, M.A. and Pacholok R. 1984. Prefabricated Masonry. Calgary: Alberta Masonry Institute, 21 pp.

Hutcheon, N.B. 1964. Principles Applied to an Insulated Masonry Wall. Canadian Building Digest No. 50. Ottawa: National Research Council of Canada, Division of Building Research, 4 pp.

Keller, H. and Suter, G.T. 1985. On the Interaction Between Masonry Veneer and Structure. Proceedings of the Third CSCE Conference on Building Science and Technology. Waterloo: University of Waterloo, pp. 119-160.

Kostiuk, L.W. and Dale, J.D. 1985. Thermal Performance of an Insulated Cavity Wall. Proceedings of the Third CSCE Conference on Building Science and Technology. Waterloo: University of Waterloo, pp. 69-98.

Kung, J.H. and Storer-Folt, J.P. 1985. Quality Control of Clay Bricks. American Ceramic Society, Ceramic Engineering and Science Proceedings, Vol. 6, No. 11-12, pp. 12-21.

Latta, J.K. and Ritchie, T. 1976. A Survey of Some Problems with Brick Masonry Buildings. Building Practice Note No. 2. Ottawa: National Research Council of Canada, Division of Building Research, 21 pp.

Longworth, J. and Warwaruk, J., Editors. 1983. Proceedings of the Third Canadian Masonry Symposium. Edmonton: University of Alberta.

Masonry Council of Canada. 1982. Guide to Energy Efficiency in Masonry and Concrete Buildings. Toronto: Masonry Council of Canada.

McGinley, G.W.; Warwaruk, J.; Longworth, J.; and Hatzinikolas, M. 1985. The Effect of the Tie Type on Brick Veneer Walls. Proceedings of the Third CSCE Conference on Building Science and Technology. Waterloo: University of Waterloo, pp. 161-176.

Mord, G. and Kariodis, J., Editors. 1987. Proceedings of the Fourth North American Masonry Conference. Los Angeles: University of California at Los Angeles.

Plewes, W.G. 1981. Exterior Wall Construction in High-Rise Buildings: Advisory Document. Ottawa: Canada Mortgage and Housing Corporation, 73 pp.

Plewes, W.G. 1979. Masonry Bibliography 1900-1970. Washington, D.C.: International Masonry Institute, 345 pp.

Ritchie, T. 1976. Moisture Degradation of Masonry Walls. Proceedings, First Canadian Masonry Symposium, June 1976, pp. 66-71.

Ritchie, T. 1973. T.T.W. Brick Walls. Journal of Canadian Ceramic Society, Vol. 42, pp 57-60.

Ritchie, T. 1972. Water Penetration Tests of TTW Brick walls. Building Research Note No. 86. Ottawa: National research Council of Canada, Division of Building Research, 23 pp.

Ritchie, T. 1963. A Cavity Wall of Concealed Bonding Bricks. Building Research Note No. 41. Ottawa: National Research Council of Canada, Division of Building Research, 6 pp.

Ritchie, T. 1961. Cavity Walls. Canadian Building Digest No. 21. Ottawa: National Research Council of Canada, Division of Building Research, 1961.

Roussean, J., Keller, H., Drysdale, R., and Suter, G.T. Seminar on brick veneer wall systems. Canada Mortgage & Housing Corporation. (Also CCRB, ABEC, MBRC, OBEC)

Suter, G.T. and Keller, H., Editors. 1980. Proceedings of the Second Canadian Masonry Symposium. Ottawa: Carleton University.

Warrent, D.J., Ameny, P., and Jessop, E.L. 1982. Masonry Connectors: A state-of-the-Art Report Complete with Selectively Annotated Bibliography. Calgary: Centre for Research and Development in Masonry, 101 pp.

PRECAST

Canadian Prestressed Concrete Institute. 1987. CPCI Metric Design Manual. 2nd Edition. Ottawa: Canadian Prestressed Concrete Institute.

Cooper, D.R. 1982. Concrete Walls Replace Traditional Wall Systems. Engineering Journal, Spring.

Division of Building Research. 1972. Cracks, Movements and Joints in Buildings. Record of the DBR Building Science Seminar. Ottawa: National Research Council of Canada, Division of Building Research.

Fowler, John R. 1988. Overview of Canadian Practices in Architectural Precast Concrete for Building Facades. PCI Journal, Jan/Feb 1988.

Giddings, Ken. 1980. Good Design Principles for Architectural Precast Concrete. Construction Canada Magazine, Vol. 22, No. 4, July 1980, pp. 12-16.

Karpati, K.K. and Serada, P.J. 1976. Joint Movement in Precast Concrete Panel Cladding. American Society for Testing and Materials, Journal of Testing and Evaluation, March 1976.

Latta, J.K. 1967. Precast Concrete Walls - A New Basis for Design. Canadian Building Digest No. 94. Ottawa: National Research Council of Canada, Division of Building Research, 4 pp.

Latta, J.K. 1967. Precast Concrete Walls - Problems with Conventional Design. Canadian Building Digest No. 93. Ottawa: National Research Council of Canada, Division of Building Research, 4pp.

The Metropolitan Toronto School Board. 1970. Beer Precast-Precon Murray Ltd. - Vertical Skin Sub-System No. 5. The Metropolitan Toronto School Board SEF Building System. SEF T7. Toronto: The Metropolitan Toronto School Board, 3 pp.

Mo-Sae Institute, Inc. 1970. Precast Concrete Promotional Literature. Mo-Sai Institute, Inc., 8 pp.

Plewes, W.G. 1970. Cladding Problems Due to Frame Movements. Canadian Building Digest No. 125. Ottawa: National Research Council of Canada, Division of Building Research, 4 pp.

Snider, George W. 1979. Precast Concrete Cladding. Specification Associate, Vol. 21, No. 3, May/June, pp 66-69.

APPENDIX A

BUILDING ENVELOPE SURVEY - TABLE 1

GENERAL INFORMATION / WALL ASSEMBLY

BUILDING RECORD NUMBER	OVERALL RATING	LOCATE: EDMONTON	LOCATE: CALGARY	LOCATE: OTHER (RD - RED DEER, GP - GND PRAIRIE, L - LETHBRIDGE, PR - PEACE RIVER)	YEAR BUILT: 1980's	YEAR BUILT: 1970's	YEAR BUILT: 1960's	HEIGHT IN STORIES: 04 TO 06	07 TO 12	13 TO 20	21 TO 30	31 PLUS	OWN BY: AMHC (or CMHC)	OWN BY: PRIVATE	INFO BY: INVESTIGATION	INFO BY: INTERVIEW	INFO BY: PREVIOUS REPORT	MAIN STRUCTURE: C.I.P. CONCRETE	MAIN STRUCTURE: STEEL	MAIN STRUCTURE: OTHER (M - MASONRY, PC - PRECAST CONC.)	MAIN STRUCTURE: RATING	CLADDING: BRICK VENEER	CLADDING: PRECAST CONCRETE	CLADDING: STUCCO (E - E.I.F.S., MC - METAL CLAD, CB - CONC. BLOCK)	CLADDING: OTHER	CLADDING: RATING	BACKUP WALL: STEEL STUDS	BACKUP WALL: MASONRY (B - BLOCK, T - TILE (CLAY), C - CIP CONC.)	BACKUP WALL: OTHER	BACKUP WALL: RATING	TYP.: FACE SEAL	TYP.: RAIN SCREEN	VAPOUR RETARDANT: NONE	VAPOUR RETARDANT: POLYETHYLENE (mil)	VAPOUR RETARDANT: OTHER	VAPOUR RETARDANT: RATING	AIR BARRIER: NONE	AIR BARRIER: MEMBRANE	AIR BARRIER: OTHER	AIR BARRIER: RATING	WATER RESISTANCE	IN WALL INSULATION: THICKNESS mm	TYP.: BATT	TYP.: OTHER	MAT'L: GLASS FIBRE	MAT'L: OTHER	RATING
01.	■		•		81					18			•		•			•			◢	•				◢	•			◢		•		2		OK	•			OK	■	65	•		•		OK
02.	■		•		83				7				•		•			•			■			•		■	•			◢	•			2		■	•			■	■	90	•		•		OK
03.	OK	•				78				15			•		•			•			OK		•			OK	•			OK	•			•		OK	•			OK	OK	90	•		•		OK
04.	OK	•				77			9				•		•			•			OK		•			◢	•			OK	•			6		OK	•			◢	OK	90	•		•		OK
05.	◢	•			84			4	8				•		•			•			◢	•			MC	■	•			OK	•	•		•		OK	•			U	◢	90	•		•		OK
06.	OK			PR	85			6					•			•			•		OK	•				OK	•			OK		•		4		OK	•			OK	OK	90	•		•		OK
07.	■	•				75			12					•		•		•			OK			•	MC	■	•		C	◢	•			2		U	•			■	■	90	•		•		OK
08.	■		•		84				12				•			•		•			■	•				■	•			OK		•									U						
09.	◢			L		77±		6					•			•				M	OK			•		■	•	B		OK	•			•		OK	•			OK	◢						
10.	◢			L					10				•			•																									■						
11.	◢			L						16			•			•																									■						
12.	◢			RD	84				8				•			•						•				◢	•			OK		•								■	OK						
13.	OK	•				79			9					•		•		•			OK	•				OK	•			OK		•									◢						
14	OK	•					69							•		•								•		◢															◢						
15.	OK	•			84									•		•						•				OK															OK						
16.	◢	•						6						•		•																									◢						
17.	◢	•				79					21			•		•		•			U		•			◢	•			OK	•										◢						
18.	OK	•				72					28			•		•		•			U		•			OK	•			OK		•		•		OK	•			OK	OK	90	•		•		OK
19.	OK	•				75±				15				•		•		•			U		•			OK	•			OK											U						
20.	OK	•				75±				20				•		•		•			U		•			◢	•			OK											◢						
21.	U	•					63			13				•		•																									U						
22.	◢	•					63				28			•		•								•		OK	•			OK	•										◢						
23.	OK	•			90				10				•			•		•			OK	•				OK	•			OK		•		6		OK		•		OK	OK	150	•		•		OK
24	■	•			81				10				•			•		•			U	•				■	•			U		•									U						
25	■	•				79								•		•		•			OK	•				■	•			OK		•									U						
26.	◢	•							12				•			•						•				◢	•			OK		•									◢						
27.	OK			GP	81				12					•		•									MC	OK	•			OK	•			•		OK	•			OK	OK	90	•		•		OK
28.	OK	•				75			12					•		•				PC	OK				MC	OK	•			OK		•									◢						
29.	OK	•			81					18				•		•		•			OK			•		OK	•			OK	•										OK						
30.	OK	•										34		•		•																									U						
31.	OK	•					65		12					•		•		•			OK	•		•		OK	•			OK	•	•									U						
32.	■	•					±63		12					•		•			•		OK	•			MC	■		T		OK	•		•			U	•			U	■						
33.	OK	•					±63			13				•		•							•			◢		B		OK											U						
34	OK	•					63			13				•		•																									U						
35	◢	•							12					•		•																									U						
36.	■	•			81					18±				•		•								E		■	•			OK	•			•		■	•			■	■	150	•		•		OK
37.	U	•			83±				10±				•			•		•			OK			•		U	•														U						
38.	■	•				75				17				•			•	•			U				CB	■	•			OK		•		•		OK	•			OK	◢	65	•		•		OK
39.	◢	•			82					13				•			•	•			OK		•			OK	•			OK	•			4		■	•			■	◢	90	•		•		OK
40.	■	•				72					22			•			•	•			OK	•				■	•			OK		•		6		■	•			■	◢	90	•		•		OK
41.	■	•				78			11				•				•	•			OK	•	•			■	•			OK		•		•		U	•			■	■	90	•		•		OK
42.	OK	•					69			15				•			•	•			OK	•				OK	•			OK		•	•			U	•			OK	OK	65	•		•		OK
43.	■	•				70				17				•			•	•			OK		•			◢	•			OK	•			•		OK	•			■	■	65	•		•		OK
44.	■		•			78			7					•			•	•			OK	•		•		◢	•			OK	•	•		•		U	•			■	■	90	•		•		OK
45.	■	•					68			15				•			•		•		OK		•			◢	•			OK	•			•		◢	•			■	■	90	•		•		OK
46.	■					72				17				•			•	•			OK		•			◢	•			OK	•			•		OK	•			■	■	65	•		•		◢
	46	36	4	6	14	17	9	4	19	16	4	1	16	30	5	32	9	26	3	2	46	17	12	10	6	46	35	3	1	46	18	18	2	20	1	46	21	1	–	46	46		20	–	20	–	46
	11																				2					12				3						1				1	13						1
	15																				2					12				0						4				11	12						–
	18																				21					14				32						12				9	10						19
	2					6				3									15		21			7		8		9		11		13		23		29		24		25	11		26		26		26

WALL ASSEMBLY

LEGEND

G – GOOD
A – AVERAGE
P – POOR
U – UNKNOWN

■ – FAILED.
◢ – WILL FAIL IF NOT REPAIRED.
.... – NO INFORMATION AVAILABLE

BUILDING RECORD NUMBER	EXTERIOR INSULATION: THICKNESS mm	TYPE: RIGID	TYPE: NONE	MAT'L: GLASS FIBRE	MAT'L: POLYSTYRENE	MAT'L: OTHER	RATING	WINDOW: OPERATION (F-FIXED, S-SLIDER, C-CASEMENT) FRAME (W-WOOD, A-ALUMINUM, U-UNKNOWN)	WINDOW: FRAME	WINDOW: RATING	BALC.: NONE	BALC.: PENETRATES ENVEL	BALC.: RATING	PATIO DOORS: NONE	PATIO DOORS: OPERATION (S-SLIDER, H-HINGED)	PATIO DOORS: RATING	QUALITY: CONST. DOCUMENTS	QUALITY: CONFORM. TO CONST. DOC	QUALITY: QUALITY OF WORKMANSHIP	QUALITY: QUALITY OF MAINTENANCE	COST: COST OF REPAIRS PER SUITE	COMMENTS
01.			•					S		OK		Y	◢		S	OK	A	U	P	U	4,000+	POST TENSIONED SLAB PROBLEMS. WATER PENETRATION AT SLOPED GLAZING.
02.	25	•			•		OK	S	WA	◢		Y	■		S	◢	P	P	P	P	4,000	BUILDING VERY POOR. WATER PENETRATION AT WINDOWS AND BALC. POST TEN. SLAB PROBLEMS.
03.			•					S	A	OK	•			•			U	U	A	G	0	DEEP OVERHANG AT WINDOWS & GOOD MAINTENANCE PROBABLE REASON FOR GOOD CONDITION
04.			•					FS	A	OK	•			•			U	U	A	G	100	BUILDING IN GOOD CONDITION. PRECAST HAS SOME PROBLEMS. HAS HAD ROOF PROBLEMS.
05.	25	•			•		OK	C	W	◢	•			•			GP	G	G	G	600	LACK OF SOFT JOINT AT SHELF ANGLE. WATER PENETRATION AT 7 & 8 FLOOR WINDOWS.
06.	50	•		•			OK			OK	•			•			G	G	G	G	O	GOOD BUILDING.
07.			•					FS	W	■	•			•			A	U	P	U		ALL WINDOWS REPLACED. METAL CLADDING ON GIRTS INSTALLED TO PROVIDE RAIN SCREEN.
08.								FS		◢	•			•								BUILDING CANTILEVERS IN 3 OF 4 CORNERS. BRICK DISTRESSED AT CANTILEVERS.
09.																						JOINTS IN STUCCO LEAKED. CAULKED 4 YEARS AGO. OK NOW.
10.								C		■												OVERSIZED CASEMENT WINDOWS SAGGED. ALL WINDOWS REPLACED WITH SMALLER UNITS.
11.								S		■												OVERSIZED SLIDERS – LEAKED & HARD TO OPPERATE. ALL WINDOWS REPLACED.
12.																						AIR INFILTRATION FROZE PIPES FIRST YEAR IN OPERATION. FIXED NOW.
13.								FS		◢	•			•								WATER PENETRATION OF WINDOWS ON UPPER FLOORS.
14.								S		◢												SOME STRESS CRACKS IN STUCCO. SOME LEAKAGE AROUND WINDOWS.
15.								S		OK												NO KNOWN PROBLEMS BUT NOT MUCH INFORMATION.
16.								S	A	■												WINDOWS LEAKED. ESPECIALLY AT 5 & 6 FLR. REMOVED VINYL TRACK & RE-EMBEDDED INSEALANT
17.								S		■		Y	◢		S	OK						PC PANELS NEED RECAULKING. SLIDERS LEAK IN HIGH WIND.
18.			•					S		OK		Y	OK		S	OK						PC PANELS RECAULKED FOR APPEARANCE. MINOR LEAKS UNDER PATIO DOORS.
19.												Y	OK			U						PC PANELS RECAULKED.
20.												Y	OK			U						PC PANELS RECAULKED. SOLVED WATER PENETRATION PROBLEMS.
21.								FS		U		Y	U		S	■						PATIO DOORS REPLACED.
22.								S	A	■	•			•								ALL WINDOWS REPLACED.
23.	50	•			•		OK	S	A	OK	•			•								CONSTRUCTION JUST COMPLETED – NO INFO
24.											•			•							1.700	NO SOFT JOINTS – EXPLOSIVE FAILURE OF BRICKS. REPAIRED BY REMOVING 3 OR 4 ROWS EACH FLOOR.
25.												Y	U			U						EFFLORESCENCE GENERAL OVER BUILDING.
26.											•			•								BRICK WORKMANSHIP POOR. DRAINAGE PROBLEMS. CRACKS AND WINDOW LEAKS.
27.	50	•			•		OK	S	A	OK												NO PROBLEMS REPORTED.
28.												Y	■			U						LEAKS AT BALCONY.
29.												N	OK			U						SAME AS # 28 EXCEPT – BALCONIES ARE INDEPENDANT SO NO LEAKS.
30.																						NO INFORMATION.
31.																						NO PROBLEMS REPORTED.
32.																						ALL BRICK REMOVED AND REPLACED WITH INSULATED METAL CLADDING.
33.																						PC CONCRETE RECAULKED IN 1989
34.																						NO INFORMATION.
35.												Y	U		S	■						REPLACED PATIO DOORS.
36.	25	•			•		OK	S	A	■							U	P	P	U		CHEAP WINDOWS. V.B. NOT SEALED. WALLS FAILED. REPLACED WINDOWS. ADDED 3 IN. OF E.I.F.S.
37.																						NO INFORMATION.
38.	25	•			•		OK					Y	U			U	U	P	U	U	4,000	BLOCK VENEER FAILING. NOT BUILT ACCORDING TO CONSTRUCTION DOCUMENTS.
39.			•					S	A	■		Y	OK		S	OK	U	P	U	G	300–1,300	WINDOWS LEAK. NO AIR BARRIER.
40.			•					S		■	•			•			A	A	U	U	1,500–5,000	WINDOWS LEAK. NO AIR BARRIER.
41.			•							OK							U	U	P	U	2,500	RAIN PENETRATION. NO AIR BARRIER. CAULKING POOR. FLASHING POOR. RAIN SCREEN NOT FUNCTIONAL
42.			•					S	WA	◢		Y	OK		S	OK	P	A	A	G	900	MINOR MAINTENANCE PROBLEMS.
43.			•					S	A	■		Y	OK			U	U	U	A	G	1,800	AIR AND WATER LEAKAGE.
44.	25	•			•		OK	FS	A	■	•			•			U	A	A	U	4,000	AIR AND WATER LEAKAGE.
45.			•					S	A	■		Y	OK		S	◢	U	A	U	U	1,800	AIR AND WATER LEAKAGE.
46.			•					S	WA	■												AIR AND WATER LEAKAGE.
	8	8	12	1	7	–		-	-	46	13		46	13	9S		TOTAL COUNT					
							–			6			2			2	TOTAL ◢					
							–			13			2			2	TOTAL ■					
							8			9			8			5	TOTAL OK					
		26			26		26	19		18		17	17			7	TOTAL UNKNOWN					

BUILDING ENVELOPE SURVEY

Morrison Hershfield Limited
Consulting Engineers

NOVEMBER, 1990

TABLE 1

APPENDIX B

SAMPLE BUILDING DATA SHEETS

****

INNOVATIVE HOUSING
BUILDING ENVELOPE FAILURE STUDY

SURVEY QUESTIONNAIRE

****

Interviewed by :__________ Visit __ Phone __ Date :__________

Name and title :______________________________________ Phone :__________

Firm and location :____

****

Number of medium and high rise buildings in portfolio :____________________

Range of ages of buildings :____

Types of wall systems (in order of most to least prevalent)

1)____________________ 2)____________________ 3)____________________

4)____________________ 5)____________________ 6)____________________

Wall discussion :____

____

____

____

____

____

Window discussion :____

____

____

____

Solutions attempted and success rate :____________________________________

____

____

____

Capital Expenditures on repairs :____

____

Notes :____

____

____

____

____

____

____

____

INNOVATIVE HOUSING
BUILDING ENVELOPE FAILURE STUDY

BUILDING DATA SHEET

1. BASIC INFORMATION

1.1 Information obtained by: ______________________________

1.2 Information obtained from: ____________________ Tel: __________

1.3 Building Name: ______________________________

1.4 Building Address: ______________________________

____

1.5 Building Owner: ______________________________

1.6 Construction Completion Date: ______________________________

1.7 Consultants

Architect ______________________________

Structural ______________________________

Mechanical ______________________________

Electrical ______________________________

Other ______________________________

1.8 Contractor: ______________________________

1.9 Building Documentation Available

	Yes	No	Tender Set	As-Built
Architectural Dwgs.	___	___	________	________
Structural Dwgs.	___	___	________	________
Mechanical Dwgs.	___	___	________	________
Electrical Dwgs.	___	___	________	________
Specifications	___	___	________	________

2. SITE INFORMATION

2.1 Grade (describe) ______________________________

____

____

2.2 Abutting or Adjacent Structures ______________________________

Which faces? ______________________________

Higher or lower? ______________________________

(describe)

2.3 Temperatures (from Bldg. Code)

2.3.1 January 1% ^{O}C: ______________________________

2.3.2 July 2.5% Dry ^{O}C: ______________________________

2.4 Relative Humidity (from Bldg. Code)

2.4.1 Mean January Vapour Pressure: ______________________________

2.4.2 Mean July Vapour Pressure: ______________________________

2.5 Precipitation (from Bldg. Code)

2.5.1 15 min rain, mm: ______________________________

2.5.2 One day rain, mm: ______________________________

2.5.3 Annual rain, mm: ______________________________

2.6 Hourly Wind Pressures (from Bldg. Code)

2.6.1 1/10 KPa: ______________________________

2.6.2 1/30 KPa: ______________________________

2.6.3 1/100 KPa: ______________________________

2.7 Prevailing Winds Summer: ______________________________

Winter: ______________________________

2.8 Air Pollution: ______________________________

3. BUILDING DESCRIPTION

3.1 Size and Shape (sketch, include orientation).

3.2 Number of Stories

- Above grade ______________________________
- Below grade ______________________________
- Total Height above grade ______________________________

3.3 Area

- Ground Floor Plate ______________________________
- Total Floor Area ______________________________

4. WALL SYSTEM (describe)

4.1 Cladding type ______________________________

4.2 Back-up wall type ______________________________

4.3 Insulation (type and location) ______________________________

4.4 Vapour Barrier ______________________________

4.5 Air Barrier (describe intent) ______________________________

4.6 Performance Problems

- describe for each symptom attempting to answer questions:

Where on building is symptom visible?

When does it appear?

When was it first noticed?

What has been attempted to alleviate the problems? Did it work?

Have any reports or investigation of problem been carried out?

If so by who?

CHECK MASONRY CLADDING - PERFORMANCE PROBLEMS CHECKLIST

CRACKING AND SPALLING

- Freeze/thaw action
- Rotation of shelf angle, due to inadequate stiffness or insufficiently fastened bolts
- Lack of expansion joints
- Excessive deformation of the structure, causing compressive loads on non-load bearing masonry and buckling panels
- Accidental lateral loading of a veneer
- Differential movement between wythes
- Thermal expansion at corners
- Discontinuities in the shelf angle

EFFLORESCENCE AND STAINING

- Rain penetration
- Moisture movement through brick

CORROSION OF TIES

- Rain penetration
- Use of non-corrosion resistant ties

RAIN PENETRATION

- Poor mortar joints, or poor bond between mortar and masonry units
- Clogged or missing weep holes
- Poor detailing at parapet
- Porous masonry
- Missing or damaged flashing
- No pressure equalization of "Rain Screen"

CONDENSATION

- Lack of air barrier, resulting in air leakage
- Lack of vapour barrier

EXCESSIVE HEAT LOSS

- Lack of insulation, or improper placement of same
- Thermal bridging at floor slabs
- Excessive air leakage

OTHER

POOR THERMAL PERFORMANCE/CONDENSATION

- ______ Lack of or improper sized thermal breaks
- ______ Incorrect insulation placement
- ______ Large exposed metal surfaces to exterior
- ______ Interior gaskets insulate glass edges
- ______ Excessive air leakage
- ______ Lack of open exposure to interior air

EXCESSIVE WATER PENETRATION

- ______ Exterior caulking failure
- ______ Loss of gasket compression
- ______ Incomplete interior seals, improper installation
- ______ Blocked drainage paths
- ______ Loss of clamping on gasket system (leading to it decline in use)

GLASS FAILURE

- ______ Wind load, thermal effects manufacture
- ______ Improper insulation placement (spandrel)
- ______ Improper glazing allowances (metal contact)
- ______ Moisture on insulation glass seals (exfiltrating air or water infiltration)

SEALANT FAILURE

- ______ Incompatible sealants or substrates
- ______ Immersion in water
- ______ Improper joint design to allow for movement
- ______ Staining, dirt pick-up
- ______ Pumping out of glazing tapes

CORROSION

- ______ Dissimilar metal contact
- ______ Improper grades of stainless steel fasteners

CHECK	PRECAST CONCRETE CLADDING - PERFORMANCE PROBLEMS CHECKLIST
	APPEARANCE
______	• Impact damage
______	• Spalling of exposed aggregate due to freeze-thaw
______	• Rust stains from ferric inclusions in aggregate
______	• Rust stains due to insufficient cover to reinforcing steel
______	• Crazing of plain concrete finished surfaces
	CRACKING
______	• Stress concentrations due to insufficient reinforcing
______	• Excessive restraint of panels, preventing thermal movements or differential movements between structure and cladding
______	• Load imposed on the structure at inappropriate locations
______	• Cracking of poured joints due to inadequate reinforcing or bond failure
______	• Shrinkage cracking of grouted joints
______	• Frost expansion of trapped moisture
______	• Cracks around faulty patching
	CONNECTIONS
______	• Pulled-out hardware due to insufficient reinforcing or incorrect location of hardware
______	• Diagonal cracks under load bearing connections, due to insufficient reinforcing
______	• Corrosion due to leakage or condensation
______	• Cracked welds
______	• Backed-off nuts or bolts
______	• Unauthorized modifications to suit field conditions
______	• Restraint in sliding connections
	INSULATED PANELS
______	• Cracks due to restraint of differential thermal movements
______	• Bowing due to differential thermal movements
______	• Displacement of outer wythe due to failure of shear ties
	JOINTS
______	• Cohesive failure of sealant
______	• Adhesive failure of sealant
______	• Squeezed-out caulking due to shortening of the structure
______	• Variations in joint widths due to erection misalignments
______	• Variations in joint widths due to movements in the structure
______	• Spalled edges at tight joints
______	• Missing or closed drain holes
______	• Dislocated gaskets
______	• Excessive weathering of caulking or gaskets
______	• Insufficient compression of gaskets
	LEAKAGE
______	• Water leakage due to condensation
______	• Water leakage from rain and snow
______	• Air infiltration/exfiltration due to gaps in the air barrier

FIELD ASSEMBLED PANELS

CHECK	SHEET METAL SYSTEMS - PERFORMANCE PROBLEMS CHECKLIST
	EXCESSIVE AIR LEAKAGE
____	• Improper joining of the joints of the factory sealed upturned edges of the inner panels
____	• Incomplete sealing of the upturned edge joints modified at non-typical corners and intersections
____	• Incomplete sealant application between adjacent sheets of flat liner steel
____	• Bond failure of the factory applied sealant due to pumping of the inner panel prior to the application of the sub-girts and the exterior steel panel
	REDUCTION IN THERMAL RESISTANCE
____	• Wetting of glass fibre insulation prior to the application of the exterior sheet steel
____	• Compression of the insulation thickness between the inner and outer sheets of steel
	CORROSION OF FASTENERS AND PANELS
____	• Galvanic reaction between dissimilar metals
____	• Improper galvanizing or application of paint finish
____	• Damage prior to the installation on the building
	STAINING AND DISCOLORATION OF EXTERIOR PANELS
____	• Continual wetting of the panel surface and deposition of chemicals
____	• Fading of the colour and eventual release of paint pigment resulting from UV absorption
____	• Streaking due to corrosion of steel fasteners
	AESTHETIC DISFIGURATION OF EXTERIOR PANEL
____	• "Oil-Canning" due to excessive wind pressure
____	• Mechanical damage caused by projectiles